DEUTSCHE BUNDESBANK
EUROSYSTEM

International Cash Conference 2019

Cash in the age of payment diversity

Content


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Johannes Beermann
Back to the roots: cash and its core functions

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Member of the Executive Board of Deutsche Bundesbank

1 Introduction

Good morning ladies and gentlemen,

It is a great pleasure to welcome you to this year's International Cash Conference. As the member of the Executive Board of the Deutsche Bundesbank responsible for cash management, I am particularly delighted to see the active research agenda that all of you are pursuing in the field of cash. This made it both difficult and easy for us to put together this year's programme. Easy because we had many contributions to choose from, and who doesn't like choice? Difficult because who said that making choices was easy?

I would like to thank all of my colleagues from the Directorate General Cash Management who have helped organise this event or who are taking part as presenters. Also, I would like to wish a particularly warm welcome to our keynote speakers, Lars Feld and Bill Maurer. We greatly value the insights that you are bringing to this year's conference and I look forward to being part of the discussion with you in the panel soon.

Today's first session especially benefits from the contributions of our guest of honour, De Nederlandsche Bank. The Dutch central bank is one the leading institutions with regard to research in the field of cash management in the Eurosystem and I look forward to hearing more about the various links between research and operational aspects. No doubt, there is currently a rather active strand of research into distributed ledger technologies and various forms of digital money.

This interest is no longer confined to "quirky" IT start-ups. Central banks and international organisations are increasingly forming innovation labs to better understand how these technologies could be of "use to the greater public". So far, these endeavours have been largely confined to conceptual proofs of concept and explorative, mostly theoretical considerations. But they are important, and research into cash is bound to benefit from these insights as well: The closing session on Thursday will give us a first glimpse of the neurometrics applied to banknote design and the potentially digital future of cash.

As exciting as these new technologies may be, a key insight that I have taken away from the discussions I have had over the last couple of years in my role is that people care a lot about the coins and banknotes they keep in their pockets. Cash is something that everyone understands and has a view on.

Research, of course, has to go beyond mere expressions of opinion. Central bankers and researchers in the area of cash need to understand the fundamental drivers of cash circulation and establish microeconomic evidence on cash usage. Cash passed the conceptual stage centuries ago. It has been around ever since. Cash is the only legal tender and, as such, it forms the basis for its cashless alternatives.

Going "all cashless" without the backing of a national unit of account is difficult to imagine. There always has to be the option to convert deposits into legal tender and the other way around. That is why research on cash is at least as relevant as ever. In a way, this means going back to the roots and asking the fundamental questions. As the title of this year's conference suggests, we are living in the age of payment diversity. Diversity is actually a concept derived from sociology. It implies that you recognise individual characteristics and allow for the inclusion of a range of people or objects.

Cash has several of those unique characteristics which greatly add to the diversity of existing payment instruments. First and foremost, cash is money because it fulfils fundamental macroeconomic functions. It acts as a store of value, a medium of exchange and a unit of account. Let us briefly go through these well-known textbook functions in turn to see what they imply with respect to cash usage.

2 Cash as a store of value

Ladies and gentlemen,
As we will be talking over the next couple of days about cash usage in different countries, allow me to set the scene a little bit for Germany. Central banks "make money" in quite the literal sense. The physical banknotes we produce are our main output and, as such, straightforward to measure. The value of euro banknotes in circulation is growing in line with, but faster than, aggregate production in the euro area. By the end of 2018, total banknote circulation exceeded 1.2 trillion euros, and it is still on the rise.

Just like any other commodity, cash gets around. It crosses borders and switches hands. A considerable chunk leaves the euro area altogether. At the end of the day, about one-quarter of the total value of banknotes in circulation remains in Germany, which is roughly in line with the domestic economy's share of aggregate euro area output.

Of course, households use cash for transactions, but they use it even more so as a store of value. Our estimates for Germany suggest that around three out of four banknotes held domestically end up under the proverbial mattress or–perhaps for greater security–in a safe deposit box. The relatively high importance of the store-of-value function of cash has remained largely unchanged since the introduction of the euro as legal tender. German households value the existence of a safe and liquid asset.

Cash is especially reliable in that regard, and in an environment of low interest rates, the opportunity costs of holding this asset decrease. While credit institutions' cash holdings are increasing, reflecting special monetary policy effects, we need to see matters in perspective:

- Banks' additional cash holdings in Germany since 2015 amount to 22 billion euros, or relative to current cumulative net issuance by the Bundesbank, about 3%.
- This leaves 97% of banknotes in circulation for foreign demand, use as a domestic store of value by households or overall domestic transactions demand.

3 Cash as a means of payment

Ladies and gentlemen,

That leads us directly to the second main function of cash, which is making payments.Cash is unique in that it is the only means of payment which is non-electronic. This limits its typical use to point-of-sale transactions, where cash usage in countries such as Germany, Austria, Spain and Italy continues to be high by international standards.Evidence for the euro area as a whole suggests that, in 2016, cash payments accounted for more than half of the total value of euro payments at the point of sale.[1] Payment technologies are continuing to evolve. The rise of

1 H. Esselink and L. Hernández (2017), The use of cash by households in the euro area, ECB Occasional Paper Series, No. 201, November 2017.

contactless payments and what are known as stable coins are likely to shake up the relative shares of payment instruments even further. Does this mean that households are willing to give up cash as a means of payment altogether?

The empirical evidence I have seen and the conversations I have had do not leave me with that impression. One reason which frequently comes up is concerns over the protection of personal privacy.

– People want to carry out a certain number of transactions without leaving a trace, making sure businesses and other institutions cannot "connect all of the dots at all times".
– In my view, this has nothing to do with potentially "shady activities"–maintaining a certain level of personal privacy is a basic human desire.

Leaving the numerous and still open questions concerning operational aspects to one side, I therefore do not believe that stable coins such as Libra have the power to crowd out cash altogether any time soon.

Still, and in keeping with the spirit of diversity, I do see potential benefits behind such new payment instruments. Those relate, in particular, to the segment of person-to-person payments, or P2P transactions. I find it remarkable that cash dominates to such an extent when it comes to payments between individuals, such as in-home services and giving money to relatives, friends, churches or other charity organisations.

– Our latest payments study suggests that 93% of the value of all P2P transactions in euro was attributable to cash payments.[2]

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2 Deutsche Bundesbank (2018), Payment behaviour in Germany in 2017–fourth study of the utilisation of cash and cashless payment instruments.

This may also reflect the still fragmented payments landscape in Europe. To date, cash remains the one truly universal means of payment when it comes to P2P transactions in the euro area. But again, we have to see matters in perspective: the total amount of P2P cash transactions in euro is fairly small, amounting to about 4% of all cash payments in the euro area.[3]

4 Cash as a unit of account

Ladies and gentlemen,

Cash increases the diversity of payment instruments by offering several unique features: it is tactile and does not require any technical equipment. It is this haptic nature of cash which, in my view, is an important element of ensuring financial inclusion. Cash as a means of payment is easily understood across the generational divide. To me, this is closely associated with the third core function of cash, which is serving as a unit of account. Universally accepted currencies are not a new phenomenon: be it gold during the gold standard, the pound sterling during the Industrial Revolution or the US dollar to this day, all have served as major internationally accepted units of account. Households value currencies they can count on and, more importantly, count with. There is arguably an important element of economic education underlying physical legal tender.

– We all have grown up playing board games, exchanging and counting paper money with our hands.

Cash bridges generations. When we at the Deutsche Bundesbank open our doors to the general public as part of our efforts to inform people about the tasks we perform within the Eurosystem, the display of actual cash and gold at our stalls

3 H. Esselink and L. Hernández (2017), The use of cash by households in the euro area, ECB Occasional Paper Series, No. 201, November 2017.

attracts visitors both young and old. These physical items serve as the first point of entry into the often abstract world of monetary policy. But, how is the increasingly widespread use of e-wallets and mobile payment apps impacting on households' financial literacy? Are children still able to grasp the educational aspect of cash in an increasingly digitalised payments landscape?

- After all, there may be parallels to the digital transformation of the reading experience. Research suggests that readers retain less information from e-books than from traditional paper books.
- I feel these are relevant questions which deserve further investigation, and I would urge all of you, too, to look into these at future meetings of the International Cash Conference.

5 Conclusion

Ladies and gentlemen,
Money is what money does. Based on the core functions of money, cash is money. That is not to say that there cannot and will not be other forms of money. True diversity implies co-existence. Cash has unique features which point towards its continued high usage in the euro area.

- As central bankers, it is our task to always maintain the public's trust in euro cash.
- As researchers, we need to understand the core functions of money in the digital era.

Cash is the natural starting point and the relevant benchmark in comparisons with other payment instruments. I now look forward to having fruitful discussions with all of you. I hope you have a great time at the conference here in Munich and are able to exchange many valuable insights and ideas.
Thank you.


EUROSYSTEEM
Coen Voormeulen
De Nederlandsche Bank

Coen Voormeulen
The Future of Cash

Coen Voormeulen
De Nederlandsche Bank

Thank you Dr. Johannes Beermann for your kind introduction. We really appreciate your invitation as this year's guest of honour.

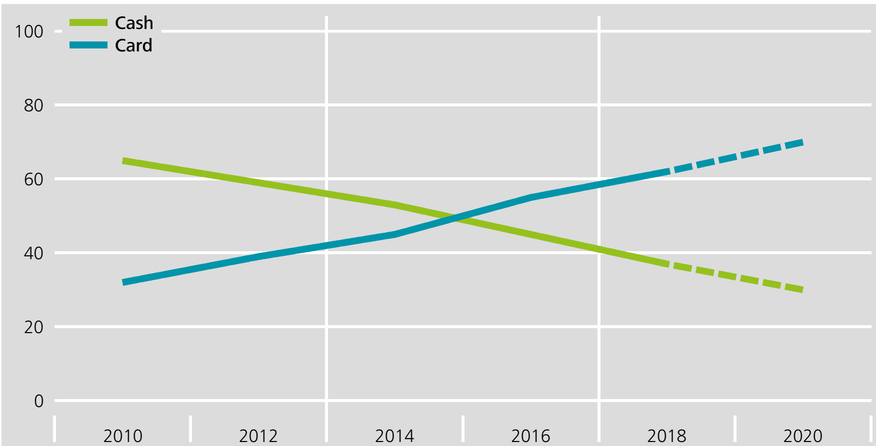
The theme of the conference is "cash in the age of payment diversity". Indeed a well-chosen motto, reflecting the spirit of the times. All of us are aware that cash is losing ground to a variety of digital payments and is therefore facing changes. The future of cash is a frequently heard topic, and I will share some of our thoughts about the strategic steps we are taking to manage the decline of cash.

Looking at the use of cash in the Netherlands at Points of Sale (POS), it is clear that it is declining fast. The popularity of electronic payments, particularly in their most recent form as contactless payments, has resulted in an average cash use at POS of 37% last year (*Figure 1*). In Germany the equivalent percentage is much higher, close to 80% (*Figure 2*).

Cash and card usage in the Netherlands at POS

Figure 1

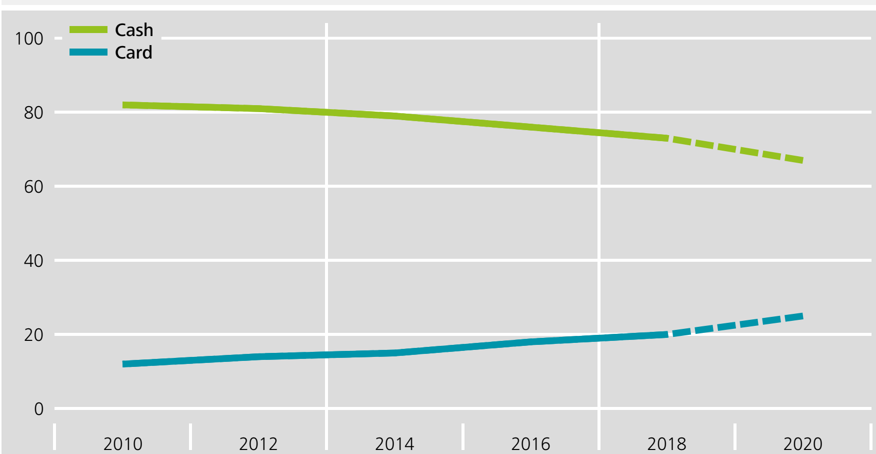
percentage of cash payments



Cash and card usage in Germany at POS

Figure 2

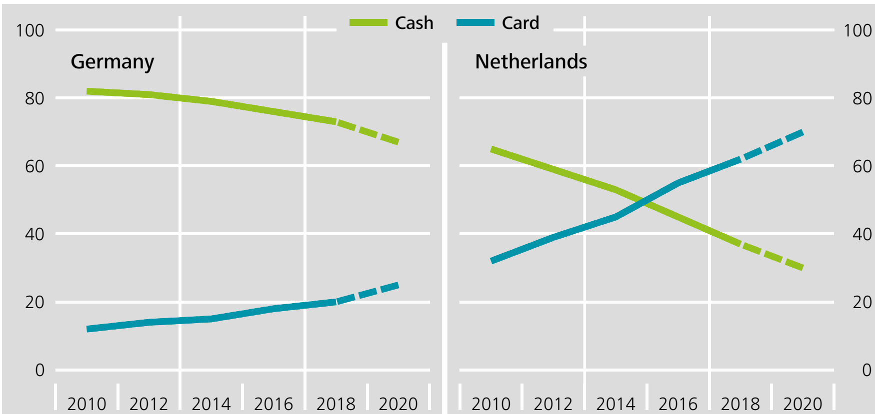
percentage of cash payments



Connecting cash and card usage in Germany and the Netherlands

Figure 3

percentage of cash payments

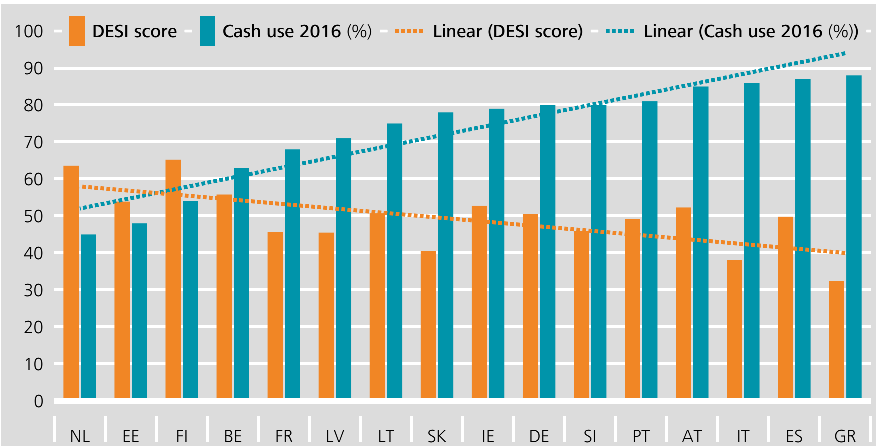


The latter is often seen as related to cultural factors, e.g. that German citizens attach more importance to privacy and hence attach a high importance to cash: cash is freedom. Although this may be true, I expect that the developments in the Netherlands will also happen in Germany. If we put the graphs of the two countries alongside each other (*Figure 3*), it suggests that Germany will follow trends in the Netherlands, albeit just a few years later. The reason for this is that the decline of cash seems to be related to the digitalization of countries. Comparing the so-called DESI-index for digitalization shows an inverse relationship with the use of cash (*Figure 4*). This inverse relationship is even stronger when cash use and internet penetration are compared (*Figure 5*). So unless Germany does not increase its level of societal digitalization, cash use there will also see a sharp decline.

De Nederlandsche Bank (DNB) considers that cash has an important role in society, even if its use is in decline. Therefore, the cash infrastructure should continue to function properly. In general, people should have a choice how they want to pay

Digitalization of several countries according to the DESI-index Figure 4

comparing DESI index with cash usage (2016)



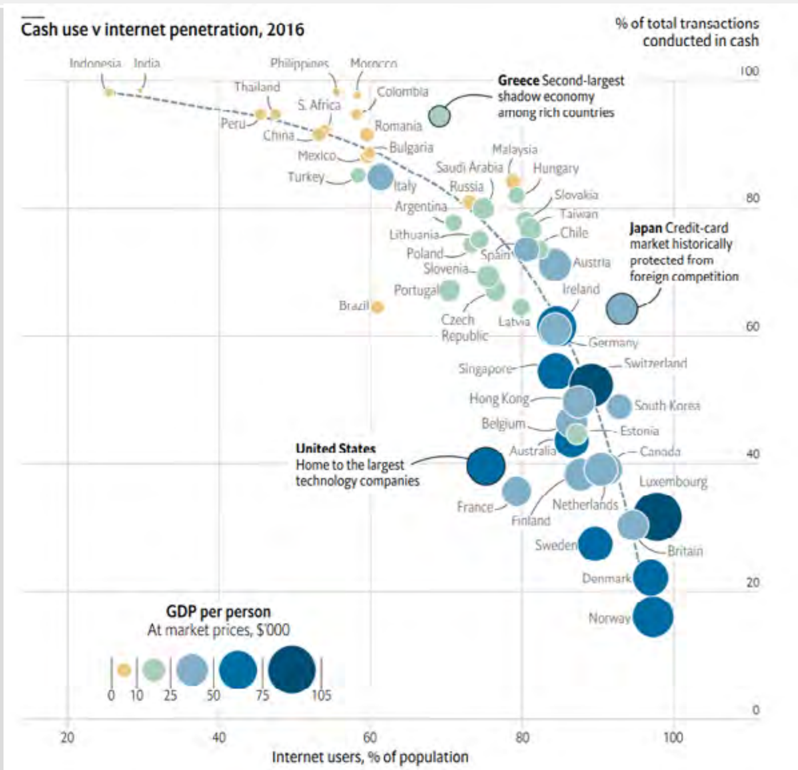
at the POS, either by cash or card. I fear, however, that public authorities taking a wait and see attitude will heighten the risk that cash will disappear. Why is that?

First of all: the fact that 37% of POS transactions are paid in cash does not mean that every person pays for roughly 37% of their transactions in cash. There are wide differences between different user groups. We can distinguish four groups: the cashless user, the hybrid user, the cash lover and the digitally incapable:

– Cashless users are mostly younger people who almost exclusively pay by card. They consider that more practical (no wallet is necessary to carry the cash). Moreover, they look at money in a different way than older generations: older people see cash as their money and the bank account as a way to store it. Younger people regard the bank account as their money and cash as a way to use it. For them, withdrawing cash from an ATM is already a way of spending their money.

Cash usage versus internet penetration for several countries

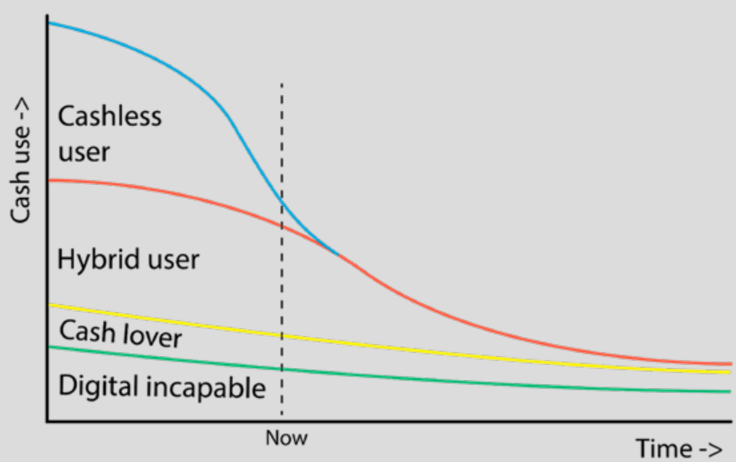
Figure 5



Source: High internet use and state support help countries ditch cash. The economist. 1 August 2019.

– Hybrid users use both cards and cash, depending on what they consider practical in a particular situation. I consider myself a hybrid user, and the reality is that I pay increasingly by card.
– Cash lovers are people who attach a lot of importance (e.g. for privacy reasons) to pay by cash.

Four different types of cash users Figure 6



- The digitally incapable are people who find it difficult to use cards, maybe because they are unable to remember their PIN code or to use cards due to a physical handicap.

Figure 6 shows how the use of cash by these groups could evolve over time. The issue at hand is whether cash would decline to a level that is still sustainable over the longer term, or whether the fixed costs of such a level would make cash in fact too expensive.

If we look at how the size of the cash infrastructure is evolving, in terms of the number of ATMs, we can see that over the last couple of years the number of ATMs has declined at a lower rate than cash use. In the Netherlands we are currently seeing a steeper decline in the size of the infrastructure. The reason for this is that the three major banks covering more than 80% of bank ATMs in the country have decided to merge their ATM networks into one consolidated network: *Geldmaat*. This enables the banks involved to reduce the number of ATMs substantially, without reducing the service levels for their customers. This is because the number of locations of ATMs stays roughly the same, but the number of ATMs in one location declines.

De Nederlandsche Bank has supported this operation because it reduces costs without reducing the level of service. The remaining number of ATMs is still sufficient. There is a question mark over how costs can be reduced further without reducing the amount of ATMs. But it is already clear that banks want to reduce the amount of ATMs further. More generally, one could argue that banks have an interest in aiming for less cash and that in particular a cashless society would be beneficial for banks. Why is that?

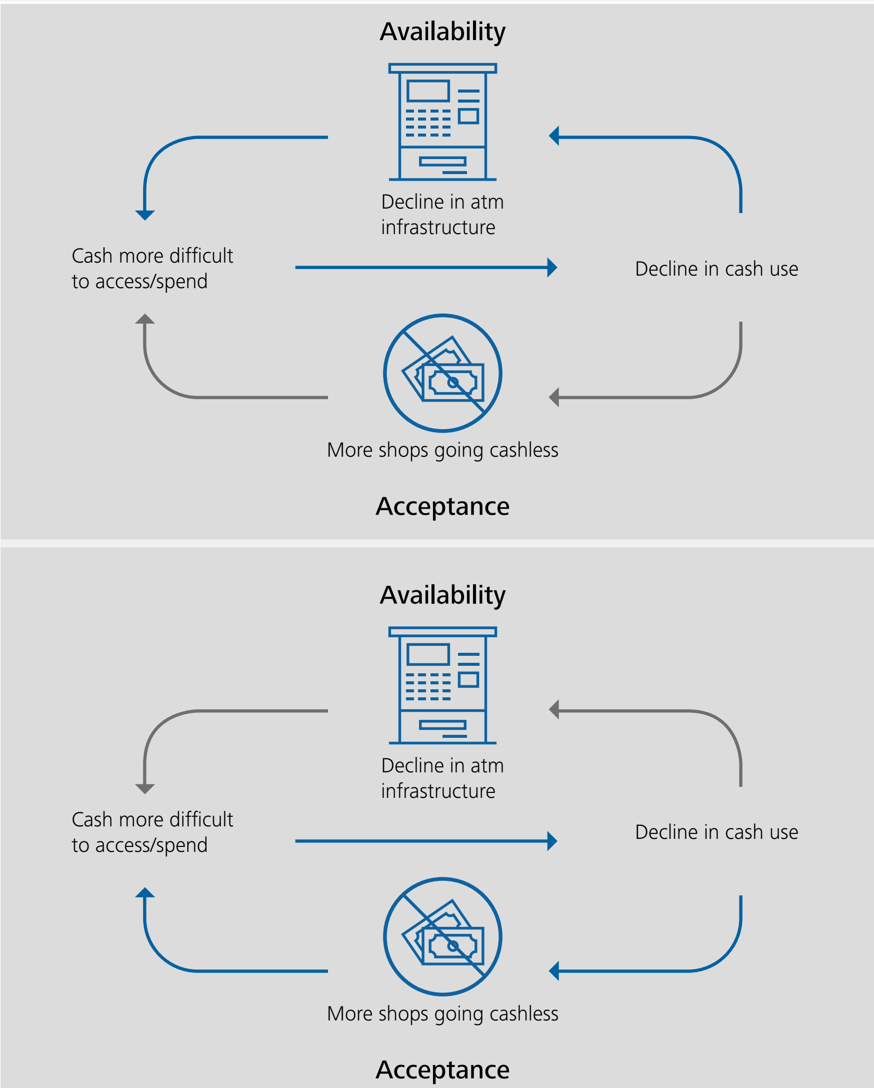
There are four reasons why banks would profit from a cashless society:

1. Removing the total cash infrastructure would reduce all the related costs of cash payments for the banks, variable as well as fixed costs.
2. If customers do not have the option to pay in cash and can only pay by card, an important competitor for card payments disappears, which might give opportunities for banks to raise the fees for card payments.
3. If customers are no longer able to withdraw cash from their bank accounts, customers are locked into the banking system. This is why a cashless society is sometimes referred to as a bank-dominated society.
4. If all POS payments are card payments, valuable information is generated which sooner or later could be used or sold.

Given these reasons, one may expect banks to keep encouraging card payments and continue reducing the size of their cash infrastructure.

Circle of cash decline

Figure 7



In such a situation, two vicious circles may occur: if cash is used less, banks will reduce the amount of ATMs, which reduces the possibility for customers to withdraw cash, so they will probably reduce their spending in cash (*Figure 7*). If cash is used less, the likelihood that more shops will stop accepting cash, increases, which will reduce the use of cash as well, and so on.

A further decline in the options for people to access and use cash implies that the core reasons for having cash is eroded: people will have less freedom of payment choice, impeding those who are dependent on cash and increasing consumers' dependency on commercial institutions. More directly impacted is the role of cash as a back-up if card systems fail. In the Netherlands, the card systems function relatively well and the availability is high. However, we all know that cybercrime is increasing and it cannot be ruled out that sooner or later major cyber-attacks might succeed. Recently the Dutch WRR–a distinguished advisory body of the government–published an extensive study concluding that, in general, the country is ill-prepared for digital disturbances. For that reason a physical back up is important. Cash is that physical back up for failing card systems. But cash can only fulfill that function if the size of the infrastructure is sufficient. Furthermore, that infrastructure should be digitally disconnected from the card payment systems.

Here an interesting question arises: what if the minimum size of the ATM infrastructure, one that would be necessary for cash to be a meaningful back up, were higher than the size the banks would prefer for commercial reasons. Who will pay for the related cost difference? In principle there are (at least) three options available: the banks, the government or the account holders:

– Option 1: One could argue that banks have the privilege of being able to create money. They are allowed to do so, but on the condition that the money they hold for their customers is also accessible to their customers, including in periods when electronic systems do not function. In other words, banks should make sure that the cash infrastructure is sizable enough so that people can have access to their money, especially in stressful periods, because that is when people need their cash the most.

- Option 2: One could argue that a part of the cash infrastructure is a public good. If the infrastructure were x% larger than banks would like to exploit based on commercial reasons, this extra x% could be seen as a public good. It has some similarity with the dykes in the Netherlands: they are in place as preparation for a crisis. The society as a whole has to pay for that. And society is represented by the government. In this option the extra size for the cash infrastructure is seen as a dyke, as a public good. And the government pays for that.
- Option 3: One could argue that the fees that customers pay for their bank accounts should reflect all the costs of those accounts. One part of those costs is to enable customers to withdraw cash from their accounts, also in stressful periods when card payments are not possible.

To conclude: I think cash continues to have an important role to play in society, for several reasons. In principle, people have to be able to choose how they want to pay: by cash or by cards. That also implies that there should be a cash infrastructure that enables people to collect cash and pay with it. It would be useful to start a discussion on whether we should indeed keep cash as a meaningful back-up for when card payments fail. At the same time, we also need to address the question of who should pay the concomitant costs. An active approach of public authorities is called for. Given the likelihood of vicious circles of cash use, an attitude of 'wait and see' risks us passing a point of no return, and cash ultimately disappearing.

Bill Maurer
Cash in an age of payment diversity: an anthropological view[1]

Bill Maurer
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This past winter, my colleagues and I conducted a short study to see what lessons about financial habits new mobile phone fintech apps were imparting to young consumers.[2] We focused on college students and staff at our university, and engaged in a two month-long study of how our subjects interacted with several budgeting and investing apps–apps like Mint and Acorns, among others.

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1 This paper is adapted from remarks delivered at the International Cash Conference 2019, Cash in the Age of Payment Diversity, 10 September 2019, Munich. I would like to thank Stefan Hardt, Hendrik Mäkeler, Nils Gerhardt, Johanna Herdt, and Correna Wagner for the invitation to present as well as for their hospitality. I would also like to thank conference participants for stimulating conversations about the present and future of cash. Jenny Fan, Melissa Wrapp, Stephen Rea, Taylor Nelms, and Carol Benson provided needed assistance, comments and criticisms. Research on payments has been supported by the National Science Foundation under grants from the Law and Social Sciences program (SES 1455859 and SES 0960423) and the Filene Research Institute. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation or the Filene Research Institute.

2 Bill Maurer, Melissa K. Wrapp, Chandra Middleton, Vivian Dzokoto, and Jenny Fan, "The Lessons of Fintech Apps: Design Matters for Personal Finance," Filene Research Institute Report No. 487, 2019, filene.org/487.

Some of our subjects were prior users of such apps; some were new to them. We recorded their existing budgeting, saving and investing habits–if, indeed, they had any–and we followed them as they began using these tools. We wanted to know, what financial literacy lessons do fintech apps actually teach? These apps are marketed as a way to help people manage their money, learn better habits, and begin to save and invest.[3] But like anything else in our app-driven and social media saturated environment, they also gather data on their users and use that data for targeted messaging–sometimes not about good budgeting or saving habits at all, but about consumption, vacation planning, and other lifestyle activities. So, we were not really surprised to see that some of the apps taught contradictory lessons: at the same time an app would encourage a user to reduce their spending on eating out, for example, it would also send them an offer for a discount at a restaurant chain, incentivizing the very behaviors the apps were teaching users to be more cautious about. At the same time that an app would provide lessons on the importance of establishing a good credit score, it would provide targeted ads for credit cards offering tailored rates or rewards.

We collected data on our subjects' existing budgeting practices, too. We'd assumed that they either had none, living paycheck to paycheck without much planning, or had some rudimentary system of keeping track of their expenses or putting money into their savings accounts or maybe even a retirement account. We'd assumed they would be using digital, or nothing at all (and, indeed, 15% were not doing anything to keep track of their finances). Over a quarter of them used some kind of digital spreadsheet to keep track of their finances. But 20% were using paper notebooks, which surprised us. We also discovered another fascinating behavior we had not been expecting. A good number of our subjects were using cash to help them save and budget.

3 See, for example, Mint's website, https://www.mint.com/.

> "Well now, like lately, I've started like taking a percentage of my paycheck or tips and then putting them away in cash, just because like I tried to do the savings account and then I had to get money out of it and it's like I keep on seeing it, so like it's hard not to touch it."

> "One of my best friends, she actually put money in a drawer that's hard to open."

We were struck in our study the extent to which digital and physical spreadsheets, paper notebooks, paper bank statements and cash worked in our subjects' financial lives to help them alternately to "see" their finances and to "hide" their money so as to keep it off limits from their daily spending. Visibility and invisibility, or, rather, techniques for making their money so, mattered more than its physical or digital status.

I think this puts an interesting spin on the current debates over cashlessness. For actual users, whether money is physical or digital is sometimes, in some circumstances and for some uses, quite simply beside the point. What matters is how, in a portfolio of manifestations of money, currency can be made more or less current, so to speak: how its flow can be slowed or shunted so that people can realize their own unique ends while participating in a money economy.[4]

Anthropologists of money recently have drawn attention to the interaction between digital technologies of payment and existing, longstanding behaviors, habits, and cultures of money in diverse contexts.[5] The research institute I direct has conducted over a hundred studies in 45 countries on people's everyday activities

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4 Our subjects' practices were reminiscent of mid-twentieth century "tin-can accounting," the practice of physically segregating banknotes as a financial planning mechanism; see Lee Rainwater, Richard P. Coleman, and Gerald Handel, Workingman's Wife: Her Personality, World, and Life Style, 2nd ed. New York: McFadden-Bartell, 1968.

5 See Bill Maurer, How Would You Like To Pay: How Technology is Changing the Future of Money. Durham, NC: Duke University Press, 2015.

with money.[6] We are particularly interested in what happens when new digital and electronic means of accessing money or paying arrive on the scene, how these new technologies get added into people's existing monetary ecologies and repertoires. What we find, consistently, across the board, is that a new digital payment service, say, Kenya's M-Pesa, does not replace existing practices or existing forms of money. Instead, it gets added into the mix, sometimes permitting new forms of earmarking or sequestering of funds but just as often facilitating old kinds of transactions in new ways. A good example is the use of M-Pesa to pool funds among users saving up for a big ritual event, only to be cashed out in a lump sum and then converted into a cow or other livestock–itself another means of saving, displaying, and exchanging wealth, as well as slowing or shunting its flow.[7]

These kinds of practices matter, we have argued, because they speak to the resilience of cash in what our conference organizers have dubbed the age of payment diversity. My colleagues and I have termed it the era of the Cambrian explosion in payments, harking back to the Cambrian period in evolutionary history that witnessed an incredible profusion of new forms of life on planet earth, a multitude of body plans and shapes occupying new niches that these lifeforms themselves created.[8]

Just as in the Cambrian period, of course, a lot of new payment forms have already gone extinct. I fondly remember COIN, the startup that ingeniously created a reprogrammable card that could emulate one's various bank cards, credit cards, loyalty cards, and so on, all in one technologically advanced form factor. Or we might think of the ahead-of-its-time, QR-code based CurrentC, a merchant-based

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6 Institute for Money, Technology and Financial Inclusion, University of California, Irvine, http://www.imtfi.uci.edu.
7 The example comes from Sibel Kusimba, Money, Mobile Money and Ritual In Western Kenya: The Contingency Fund and the Thirteenth Cow. African Studies Review 61(2):158-182, 2018.
8 Future of Money Research Collaborative (T. Nelms, B. Maurer, L. Swartz, S. Mainwaring), Social payments: Innovation, trust, Bitcoin and the sharing economy. Theory, Culture and Society 35(3):13-33, 2017.

payment platform that never really got off the ground. Aside from significant coordination problems because of the large number of retailers involved, the user experience proposal was, at the time, perplexing: people were just not used to scanning QR codes with their mobiles or imagining the mobile primarily as a screen-plus-optical-scanner. Phones–if you can remember that far back!–were for talking and texting. Now, Alipay and WeChat's phenomenally successful launch of their QR-code based payment services came about in a different consumer context, where millions of Chinese adopted mobiles at the time that they had become essentially cameras with screens. Scanning a QR code was a small jump from people's existing behavior. The companies offering these new services promoted them during Chinese New Year, too, selling them as a fun way to send digital hong bao or digital "red envelopes" containing digital money to friends and relatives for the holidays.[9]

And, again, this is a lesson we've learned now from countless other studies: leveraging existing behaviors rather than demanding users start doing something wholly new generally works well in the introduction of a new payment modality. In the case of M-Pesa, people were already using the text-message function of their simple Nokia phones. People were also using top-up cell phone credit as a means of payment: a user could buy top-up credit in the form of a small card with a secret code on it; and instead of loading up the credit into their own phone using that code, could text the code to a friend, who would then use it to top-up their own phone. And presto: something like a money transfer had taken place.[10]

The insights we gleaned from our small study of fintech apps underscore that there are many existing practices even in the highly technologized global North in which

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9 See Bill Maurer, Paying Behind the Great Firewall: Maurer Plays Marco Polo (Part 1). Blog, Institute for Money, Technology and Financial Inclusion, October 16, 2017,
http://blog.imtfi.uci.edu/2017/10/paying-behind-great-firewall-maurer.html.
10 One of the earliest accounts of mobile airtime as a form of money is Jan Chipchase, Mobile Phone Practices & The Design of Mobile Money Services for Emerging Markets, Nokia, 2009, available at https://media-openideo-rwd.oiengine.com/attachments/2faae263-bb5c-49df-bafd-ac0fba446940.pdf.

cash plays an important role. Frankly, I expect cash to continue to play these roles if not increasingly to become important as people grapple with job displacement, income volatility, and generalized economic precarity. Estimates vary, but in the United States as many as 30% of households are un- or underbanked. Increasing displacement globally, driven by climate change, war, or political instability, will also lead to more precarity with respect to people's access to banking services. Digital payment services that depend on a linkage to a bank account are going to exclude large numbers of people. There is the danger, too, that cash payment becomes stigmatized because of its association with those further down the income ladder or those experiencing some form of displacement.

Furthermore, the Silicon Valley culture driving much payment innovation proceeds very much in a bubble. Outside a few metropolitan areas in the United States, connectivity is simply not sufficient to allow for the many innovations in payment being developed. We conducted a sort of payments survey of Los Angeles–a vast, and incredibly diverse region of great wealth and great poverty. There were areas where it was simply impossible to pay if all you had in your pocket was cash. Similarly, there were areas where cash remains king, albeit circumscribed in various ways by limits on the denomination of notes that will be accepted, or by time limits on when a merchant would accept those bills ("No $100s after 10pm").[11]

In addition, growing public awareness over the way Silicon Valley has engaged in what Shoshana Zuboff calls "surveillance capitalism" is leading not only to regulatory concern but subtle shifts in consumer behavior.[12] In our small study, users of fintech apps resisted some of the key features these services offered because they wanted to safeguard their personal or bank data. Many chose not to link the apps to their bank accounts at all–thereby cutting off these apps' core functions. None of our subjects

11 See http://alippman.com/ for the Los Angeles Payments Project.
12 Shoshana Zuboff, The Age of Surveillance Capitalism: The Fight for a Human Future at the New Frontier of Power. Cambridge, MA: Harvard University Press, 2018.

made use of the social media components of these apps, which allow you to share and compete with "friends" also using the apps. A short survey of some of our participants found a gulf between the extent to which they trusted their bank or credit union–they trusted them a lot–and platform companies like Facebook or Google–whom they trusted hardly at all. This is striking given the low esteem in which many hold the banking sector. We see this same pushback against the platform companies in contemporary regulatory discussions in Europe and the US, nicely crystallized in the strong skepticism on both sides of the Atlantic to Facebook's proposed Libra project.

I think Libra is diagnostic of a broader set of problems facing the business of money. Take the current discussion over the roll out of two of the EU's core digital identity and payment directives: the General Data Protection Regulation (GDPR) and the revised Payment Services Directive (PSD2). They crystallize the dilemma facing democratic governance in an age of digital platforms: how to balance digital privacy while allowing people to take advantage of the things that having a digital identity allows. GDPR is meant to guarantee privacy. PSD2 is meant to guarantee "Strong Customer Authentication" so that third parties can use consumers' financial data to provide new services. One grants the right to be (digitally) forgotten; the other enforces strong identity authentication for the benefit of third parties. These seem pretty irreconcilable.

This is symptomatic of the political challenges posed by private digital platforms that enjoy vast power over our lives with little democratic oversight. Libra proposes to take this a step further, disintermediating money from the state ostensibly in the name of access but also digital privacy. It seems that we can't see a way to make money digital without giving away the keys to our personal privacy to a state, or submitting ourselves fully to the exploitation of digital platforms.

In the physical domain, we've solved this problem: with cash. It's worth reconsidering how cash works before we get locked into the impossible choices digital money seems to put before us. Physical banknotes allow for relatively private, anonymous transactions. Banking regulations specify banks' role in maintaining the integrity of the payments system. Governments maintain oversight of banks through independent monetary authorities mandated to function in the public interest. (This is one reason why US President Donald Trump's attacks on the Federal Reserve are so troubling–they challenge not just the independence of the central bank but the very idea of monetary policy acting in the public interest).

Platform companies like Facebook have eroded trust in such public institutions, as part of the general turn toward privatization of public services (see: Uber in relation to public transportation[13]) and through large-scale digital disinformation (see: malicious Facebook posts spreading disinformation during the 2019 protests in Hong Kong[14]). But it seems to me we have the tools at our disposal to ensure digital identity and digital money managed by private entities or consortia like Libra receives proper public oversight. If digital identity and digital privacy are animating the conversation about the nature of money today, Libra should lead us to a greater appreciation of the fact that money is a problem not to be solved with more technology, but more democracy.

And this brings us, I think, to the core of the question of cash in an age of payment diversity. Cashlessness is in one sense an effort on the part of private companies to fence off one of the last commons (as one of my interviewees in the payments industry once put it to me). As the Facebooks and Googles of the world attempt to lock users into their own walled garden and become all-encompassing, they compete over an ever-shrinking share of users' attention and the data gleaned from their behavior. GPS and other tracking technologies, augmented reality games

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13 Kate Conger, Uber Wants To Sell You Train Tickets. And Be Your Bus Service, Too. The New York Times, 7 August 2019.
14 Kate Conger, Facebook and Twitter Say China Is Spreading Disinformation in Hong Kong, The New York Times, 19 August 2019.

like Pokémon Go, and transit and lodging platforms like Uber and Airbnb increasingly connect users' online and physical world realities. However, cash payments at the physical world point of sale still remain out of reach of these services. And data from such transactions would be immensely valuable. Digital payment platforms for the physical world till represent a way to stake a claim on this final frontier.

The battle is over who will get there first, banks or platform companies. Brett Scott, an insightful critic of cashlessness, argues that the cashless economy is really a misnomer for the "bankful" economy, since digital payment, he says, is really another name for bank transfers.[15] I think he is essentially correct but misses the real drive on the part of platform companies not to become banks but to disintermediate them altogether, in the name of digital surveillance capitalism.

What is interesting to me as an anthropologist watching this all play out is that just as we found my college students relying on cash-based practices like putting banknotes in a sticky drawer, we are beginning to see efforts to launch a defense of cash. The idea that cash-free businesses are exclusionary is becoming more generalized. I was tickled by the trials and tribulations of the American "fast casual" restaurant chain, Sweetgreen. In 2016, it announced it would no longer accept cash at any of its establishments. Couched in hype around innovation and sustainability ("To us, innovation isn't necessarily about new technology–it's about curiosity and asking why") its announcement also noted the real, bottom-line issues involved in running a business chain–rising labor costs and rent, as well as the amount of time spent in cash handling. "Welcome to the future, baby," their press release read.

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15 Quoted in Hannah H. Kim, The Future of Cash: Will digital payment systems replace paper currency? CQ Researcher 29(26), 19 July 2019, available at
http://library.cqpress.com/cqresearcher/document.php?id=cqresrre2019071900,
and Brett Scott, "The War on Cash," The Long+Short, 19 August 2016,
https://thelongandshort.org/society/war-on-cash.

In a complete about-face, in April of 2019 Sweetgreen announced–with a much smaller degree of fanfare–that it would again be accepting cash. The press release was titled, "Back to the Future–Its Cash," and noted that while going cashless did help the company meet some of its intended goals, it had the "unintended consequence of excluding those who prefer to pay or can only pay with cash." Sweetgreen aims, the press release continued, to "democratize real food." Cashlessness was presumably at odds with such democratization.[16]

Brett Scott argues that "the spread of digital payments is … a gentrification process."[17] I sympathize with the perspective, and yet I wonder if this, limits our political imagination by foreclosing a system for digital payments that would not necessarily exclude or discriminate. What might such a system look like? For one, it would need to interoperate with cash, allowing people to move their funds freely between different modalities or forms without penalty and ideally without fees. People already seem to manage such movement, of course, with their existing portfolio of cards, mobile payment, and online payment, together with cash. This is one of the lessons of our study of app users, but we've seen it again and again in our research around the world, too. New payment technologies are additive, they rarely supplant or displace altogether another payment form. M-Pesa, as many observed after its roll out, was a bridge to cash–it did not replace cash, but rather expanded the number of cash-in, cash-out points far greater than brick and mortar bank branches had been able to provide.

So, does cash need to be protected? We certainly see moves to disallow the refusal of cash. In a recent report Ursula Dalinghaus reviews the arguments that cash has some of the qualities of public goods.[18] It is non-excludable, that is, users

16 The Sweetgreen case is discussed in Hannah H. Kim, op. cit.
17 Quoted in Hannah H. Kim, op. cit
18 Ursula Dalinghaus, Virtually Irreplaceable: Cash as Public Infrastructure. Cash Matters, International Currency Association, 2019.

don't have to pay to have access to its use, unlike, say, a fee-based or membership-based digital payment system. Cash is also non-rivalrous, as a system, insofar as my use of the cash system does not preclude your use of cash. We can't use the same banknote, but we can use the system without depriving others of its use. Cash is the only payment method at present that fulfils these functions. Shifting the discussion from Brett Scott's "gentrification" to "non-excludable non-rivalrous payment" might give us some traction in imagining a new digital payment system, alongside existing systems, as a public good.

And it's worth remembering, too, that cash is the only payment method that works without electricity or information technologies. The infrastructures that support payments of all kinds need to be kept in mind whenever we talk about cash and cashlessness, particularly when infrastructures today face new challenges, not least of which is their privatization.

There would still be problems to solve around data–what is collected, who owns it, how could it be used or not–and identity–when is its verification required, when can it be let go? Framed in terms of a robust conversation about public goods and the public interest, however, these become different kinds of questions.

I have a close relative who assumes, because I study digital payment, that I am anti-cash. He regularly emails stories about government conspiracies seeking to control our lives by peering into all our financial transactions (though he never sends similar stories about Facebook or Google's surveillance). I have colleagues who assume that because I have participated in studies of cash use and because I talk about the importance of the public interest in payment that I am pro-cash. As an anthropologist of money, my charge is to document what exists out there in the world, to understand what differently situated people are doing and why, to get a sense of how they navigate a world not of their choosing but which nevertheless provides them tools to realize their own ends. This includes asking after the discourses that structure our conversations and sometimes limit them, constraining our imagination and preventing us from thinking otherwise.

Cash in an age of payment diversity underscores that there needs to be choice in means of payment. We always have to bear in mind: others face different challenges than we do; and there is the thinnest of barriers between us and those kinds of challenges, whether from natural disasters, political upheaval, or other uncertainties once unthinkable that now are rapidly becoming the norm. If nothing else, the sense of uncertainty provides an opportunity to remember the virtues of collective, democratic enterprise, to find ways to nurture them and not so much revivify them as transform them positively for the kind of world we now inhabit and will inhabit, if we are so lucky, in the future. Across the board, there is an increasing need to defend public goods of all kinds. Cash is one of them.

Hans de Heij
Comparing Banknote Designs USD20 and EUR20 using the Quick Scan Method

Hans de Heij
De Nederlandsche Bank

1. Introduction

The 4th Internal Cash Conference was organised by the Bundesbank in Munich and took place from 10-12 September 2019. De Nederlandsche Bank (DNB) was Guest of Honour and was invited by the Bundesbank to follow an interactive approach within their presentations. DNB's suggestion to do a 'Quick Scan' on two banknote designs was welcomed and turned out to be a unique one day research experiment. This report completes the experiment.

A 'Quick Scan' card as shown in *Figure 1*, is a five point interval scale or Likert scale following the ten topics of the Upid-Model, a model representing a use-centered design approach (reference 1). The Upid-Model is divided in two groups, four User Interface Functions (UIFs) and six User Experience Functions (UXFs).

The Quick Scan was presented and explained to the international audience in the morning of 10 September 2019, as part of the Introduction presentation by

Quick Scan card
Front and Reverse

Figure 1

Quick Scan

Upid - Model — Score: Low … High

User Interface Functions	**1**	**2**	**3**	**4**	**5**
1. Recognising value					
2. Handling					
3. Checking authenticity					
4. Receiving the communication message					

User Experience Functions	**1**	**2**	**3**	**4**	**5**
1. Experiencing identity					
2. Judging aesthetics					
3. Retaining confidence					
4. Connecting with main image					
5. Expecting sustainability					
6. Linking to information technology					

Your banknote

Scored by

Date

Provided explanation of the items on the Quick Scan

Figure 2

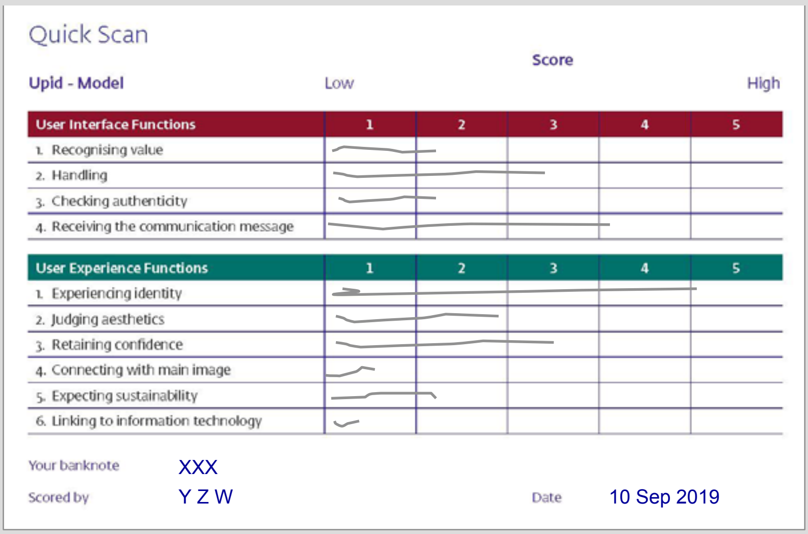
User Interface Functions	
1.	Is the value easy recognizable?
2.	Is it easy to handle?
3.	Is it easy to check the authenticity?
4.	Does the note communicate a message to you?
User Experience Functions	
1.	Is it clear which nation the note represents?
2.	Do you consider the note beautiful?
3.	Does the note provide you confidence?
4.	Do you feel a bond with the main image?
5.	Do you consider the note green/sustainable?
6.	Is the note able to interact with digital systems?

Mr. Coen Voormeulen (reference 2). The items on the card were explained by Mr. Voormeulen as shown in *Figure 2*. Subsequently, respondents were asked to fill in the Quick Scan for one banknote (*Figure 3*).

The audience was arbitrary divided in two groups, people on the left side of the room were asked to score the USD 20 and the audience on the right side the EUR 20 (*Figure 4*).

Provided explanation of filling in the Quick Scan

Figure 3



Quick Scan

Score

Upid - Model	Low				High
User Interface Functions	**1**	**2**	**3**	**4**	**5**
1. Recognising value					
2. Handling					
3. Checking authenticity					
4. Receiving the communication message					
User Experience Functions	**1**	**2**	**3**	**4**	**5**
1. Experiencing identity					
2. Judging aesthetics					
3. Retaining confidence					
4. Connecting with main image					
5. Expecting sustainability					
6. Linking to information technology					

Your banknote XXX

Scored by Y Z W

Date 10 Sep 2019

2. Results

In total 75 people filled in a Quick Scan, 39 respondents scored the USD 20 and 36 scored the EUR 20. There was a variety of the way the cards were filled in as shown in Appendix 1. Respondents could score between round numbers, for example between 2 and 3. This score was reported as 3; similarly, a score reaching into the rectangle of 3, was reported as 4 etcetera. The results were calculated during the lunch break by two DNB colleagues, Mr. Frank van der Horst and Mr. Igo Boerrigter and are presented in *Figure 5*. The original data is presented in *Appendix 2*.

Images of the two banknote designs scored Figure 4a
USD 20, issued in 2004

Images of the two banknote designs scored Figure 4b
EUR 20, issued in 2017

Results as calculated on 10 September 2019

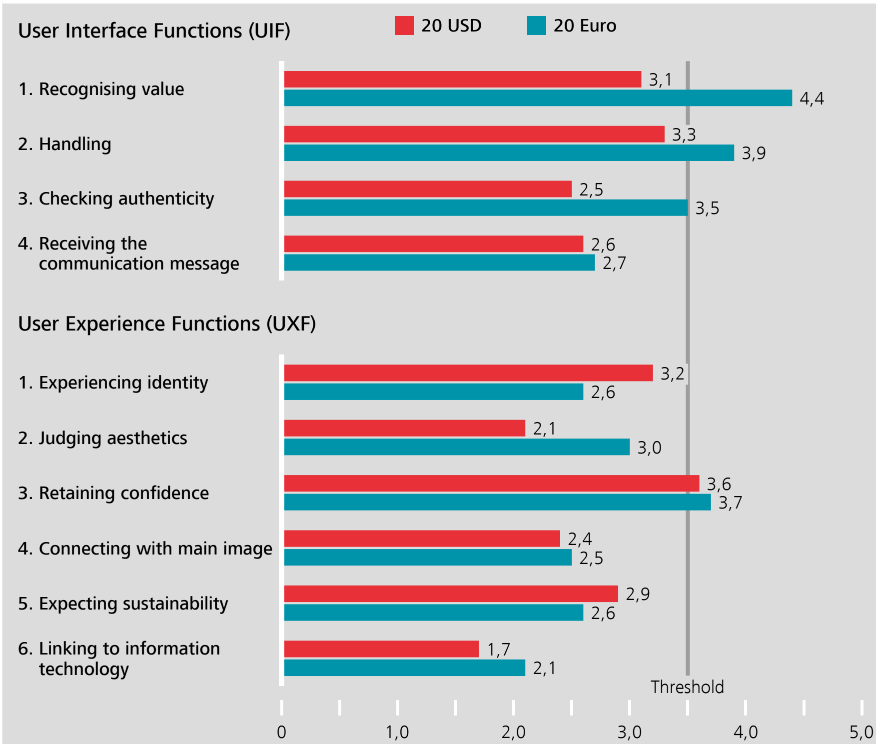
Figure 5

	USD		EUR	
User Interface Functions (UIFs)	**Score**	**Average**	**Score**	**Average**
1. Recognising value	3,1	2,9	4,4	3,6
2. Handling	3,3		3,9	
3. Checking authenticity	2,5		3,5	
4. Receiving the message	2,6		2,7	
User Experience Functions (UXFs)	**Score**	**Average**	**Score**	**Average**
1. Recognising identity	3,2	2,7	2,6	2,8
2. Judging aesthetics	2,1		3,0	
3. Retaining confidence	3,6		3,7	
4. Connecting with main image	2,4		2,5	
5. Expecting sustainability	2,9		2,6	
6. Linking to IT	1,7		2,1	
Average UIFs + UXFs		2,8		3,2

Subsequently these findings were filled in in a prepared slide as shown in *Figure 6* and were presented by Mr. Hans de Heij to the audience in the afternoon during the session of 'Modelling User Needs of Payment Instruments' (reference 3).

Results of the Quick Scan

Figure 6



Note: The results of the Quick Scan as presented at 4th International Cash Conference on 10 September 2019, a corrected and more detailed version. n(USD) = 39; n(Euro) = 36.

3. Analysis

It is striking that the scores for dollar and euro do not differ much from each other; the general average score for the dollar is 2,8 and for the euro 3,2 (*Figure 5*). Looking to the User Interface Functions, the average score for the dollar is 2,9 versus 3,6 for the euro. Zooming in on the User Experience Functions, both designs have a quite similar score, on average 2,7 and 2,8 respectively.

The highest score for the euro is 4,4 on value recognition (UIF 1). The lowest score is for the dollar with 1,7 for linking to information technology (UXF 6).

The communication message of the dollar and the euro are both not well understood (UIF 4). In line, one does not feel much with the image either (UXF 4). Confidence (UXF 3) is reasonably high in both banknotes (3,6 and 3,7 respectively). Identity (UXF 1) and sustainability (UXF 5) scores are higher for the dollar than for the euro.

The most important conclusion is that both banknote designs leave room for improvement! The central bank could at least aim for an average score of 3,5 (a 7 on the scale of 1 to 10), the threshold value indicated in *Figure 6*.

4. Conclusions

The Quick Scan Method is easily understood by the international audience present at the International Cash Conference. Most respondents have completed the Quick Scan within 5 minutes.
The data can be quickly processed, 75 cards within 1 hour, and can be presented the same day.

The differences between the two banknotes at offer are not large, both banknote designs show much room for improvement from the point of view of a use-centered design approach.

5. References

1. **De Heij, H.** (2017). A Model for Use-Centered Design of Payment Instruments: Upid-Model. Thesis. Tilburg University.

2. **Voormeulen, C.** (2019). Introduction. 4th International Cash Conference. De Nederlandsche Bank. Powerpoint. Presented at 4th International Cash Conference, Bundesbank, Munich.

3. **De Heij, H.** (2019). Modelling User Needs of Payment Instruments. De Nederlandsche Bank.

6. Appendix

Quick Scan cards filled in
9 samples

Appendix 1

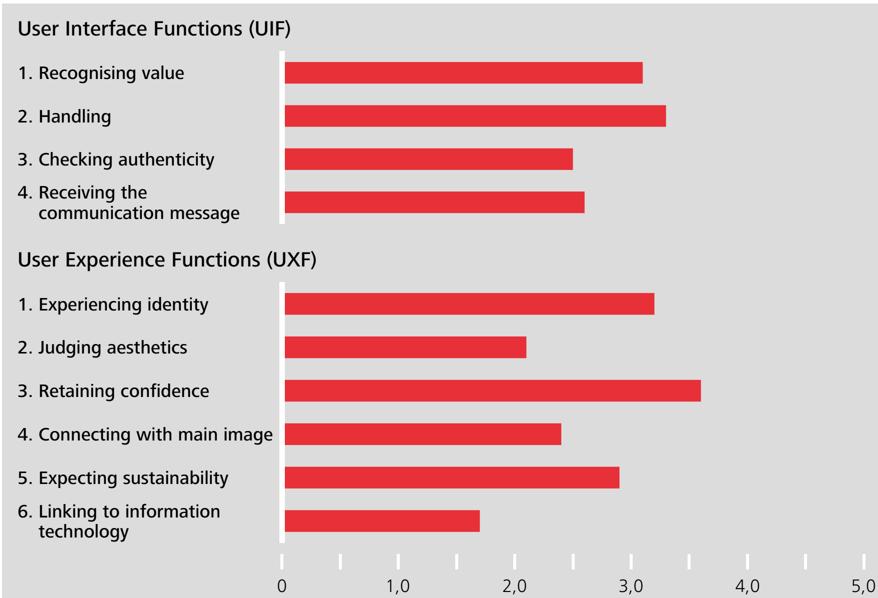
Appendix 2a

Data
USD

UIF 1	UIF 2	UIF 3	UIF 4	UXF 1	UXF 2	UXF 3	UXF 4	UXF 5	UXF 6
4	4	2	3	3	1	2	3	3	1
3	3	3	2	2	2	4	1	4	1
3	3	4	3	3	1	4	1	2	5
2	4	2	2	3	2	3	2	3	1
5	5	4	3	1	1	4	5	5	1
3	4	5	2	2	3	4	1	3	1
1	4	1	2	4	3	3	1	1	1
5	3	1	1	2	3	3	4	3	1
2	3	1	3	4	1	3	1	3	4
1	3	3	5	5	2	5	5	4	1
3	3	3	3	3	1	2	4	2	1
2	3	2	2	3	1	3	2	2	1
4	4	2	3	4	2	4	2	3	2
5	4	3	2	4	4	5	2	5	5
4	2	1	2	5	2	2	2	1	1
4	2	1	2	1	1	1	2	2	1
3	4	2	4	3	4	4	3	2	1
2	3	2	3	4	2	3	1	2	1
5	3	3	3	3	4	5	4	3	1
5	5	5	3	3	3	5	3	5	4
2	3	1	1	4	1	4	1	3	1
2	2	2	2	4	1	3	2	1	1
2	2	3	2	2	1	3	3	2	2
2	4	2	4	5	4	5	5	4	2
3	2	3	2	3	1	4	1	1	1
2	3	2	2	4	3	4	2	4	2
4	3	4	3	3	3	4	3	4	2
3,1	3,3	2,5	2,6	3,2	2,1	3,6	2,4	2,9	1,7

Appendix 2a (contin.)

Results of the Quick Scan: 20 USD



Appendix 2b

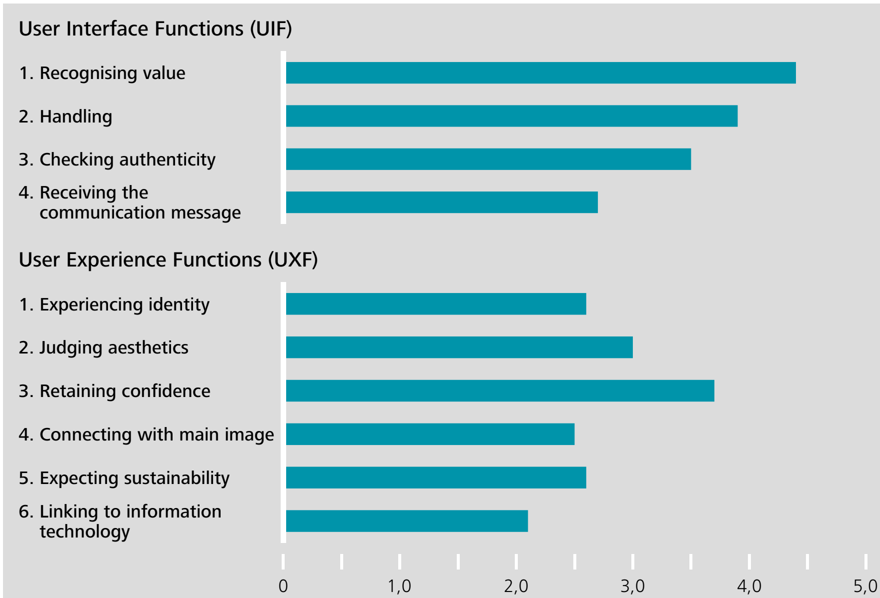
Data

EUR

UIF 1	UIF 2	UIF 3	UIF 4	UXF 1	UXF 2	UXF 3	UXF 4	UXF 5	UXF 6
4	4	3	4	2	2	3	3	2	2
4	4	5	3	3	4	5	3	3	5
5	5	5	1	2	3	3	2	2	1
4	4	1	3	4	4	3	3	3	2
4	3	3	2	3	3	4	3	3	2
5	4	3	1	1	2	4	1	2	4
5	2	2	2	4	1	2	1	2	1
4	4	4	2	2	4	4	2	3	1
3	3	3	2	2	2	3	2	2	2
5	4	3	3	2	4	4	2	2	1
4	4	3	1	2	3	4	2	3	3
5	4	3	5	2	1	3	1	3	1
5	3	4	4	4	4	4	4	3	2
5	4	2	2	2	5	4	2	1	2
3	4	4	2	1	2	3	2	3	2
3	4	5	5	3	4	5	4	5	4
5	4	5	4	5	5	5	4	4	3
4	3	4	2	4	3	5	2	3	3
5	4	4	4	2	3	4	4	2	3
5	5	3	2	3	2	4	3	2	2
4	4	4	4	3	3	3	3	4	1
5	4	3	2	1	2	4	3	2	1
5	4	3	4	4	3	4	3	3	2
5	5	5	2	2	1	2	1	1	1
4	4	3	2	3	4	3	3	2	1
4,4	3,9	3,5	2,7	2,6	3,0	3,7	2,5	2,6	2,1

Appendix 2b (contin.)

Results of the Quick Scan: 20 Euro



Till Ebner, Thomas Nellen, Jörn Tenhofen
Budget control and payment behavior: evidence from Switzerland[1]

Jörn Tenhofen
Swiss National Bank

Abstract

This paper provides distinct evidence that a budget control motive bears explanatory power for heterogeneous payment behavior among consumers in Switzerland. The analysis based on survey data indicates that consumers use payment instruments to control their budget either through "pocket watching" or through "digital watching". "Pocket watchers" reveal a higher cash usage, a lower number of non-cash payment instruments, a higher switching threshold, a higher average withdrawal amount and a higher withdrawal trigger than other consumers. "Digital watchers" exhibit the opposite payment behavior.

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1 The paper benefitted from comments and suggestions by Katrin Assenmacher, Martin Brown, Peter Eltschinger, Petra Gerlach, Beat Grossenbacher, Carlos Lenz, Antoine Martin, Franz Seitz, Helmut Stix and Andy Sturm. We are grateful to participants of the SNB Brown Bag Seminar and the International Cash Conference 2019 by Deutsche Bundesbank. The views, opinions, findings, and conclusions or recommendations expressed in this paper are strictly those of the authors. They do not necessarily reflect the views of the Swiss National Bank. The SNB does not take responsibility for any errors or omissions in, or for the correctness of, the information contained in this paper.

1. Introduction

Cash keeps its allure. In many economies, cash is still widely used for day-to-day transactions (Bagnall et al., 2016, Jobst and Stix, 2017). This contrasts starkly with the increased availability, diffusion and widespread acceptance of non-cash means of payment and the significant information technology-driven innovations in the electronic payment infrastructure that have taken place.

One reason for the stickiness of consumers' cash usage and thus of cash demand faced by central banks is the distinct feature of cash to represent memory: a glance into one's pocket gives a signal of the remaining budget and past expenses. Hence, cash usage reduces budget-monitoring costs (Krueger and Seitz 2018, Hernandez et al., 2017). Von Kalckreuth et al. (2014, vKSS) provide a theoretical framework to analyze this proposition empirically. They claim that for consumers who have an "elevated need for spending control" and "limited information-processing capabilities" it is optimal to adhere to a "pocket watching" strategy, i.e. to use cash as their main payment instrument and to show a cash-intensive payment behavior more generally. This has implications for future cash demand. In particular, if cash exhibits certain features or provides certain services which cannot easily be replicated by other means of payment, then a full transition to a cashless society is less likely and central banks are likely to face a persistent base demand for cash as a means of payment.

Based on German survey data from 2008, vKSS provide evidence that being a "pocket watcher" or being a "restricted consumer" – defined as having an elevated need for spending control and low information processing capabilities – bears explanatory power for the heterogeneity across consumers in payment behavior. They show that this holds even when controlling for other, often-cited drivers of payment behavior such as socio-demographic characteristics. Against this background, vKSS conjecture that cash is unlikely to lose much of its importance for restricted consumers.

This paper makes two contributions to the literature on payment behavior. First, we re-validate vKSS' theoretical framework providing evidence in terms of pocket watchers' payment behavior. This is valuable for various reasons: One, to classify consumers as pocket watchers, we use a complementary definition to vKSS. Specifically, we base our classification on consumers' self-assessment of their motives for their payment instrument choice. Two, as we make use of more recent survey data, our evidence is particularly insightful against the background of a steadily increasing penetration of non-cash payment instruments and innovations in payment instrument technology since 2008. Specifically, we analyze questionnaire responses and payment diary data provided by a survey on payment methods conducted by the Swiss National Bank in the second half of 2017 (SNB, 2018). Three, we provide evidence that is based on payment survey data from a different country, namely Switzerland.

Our empirical analysis suggests that cash as a monitoring device remains a valid explanation for the heterogeneity in payment behavior. Indeed, pocket watching is a widely adopted strategy among consumers in Switzerland. According to our classification, 18% of consumers motivate their cash-intensive payment behavior by its self-assessed usefulness as a budget control device. Hence, our finding that pocket watchers exhibit a cash-intensive payment behavior along several dimensions validate the vKSS framework: Pocket watchers have a high probability of always paying cash for amounts up to CHF 100 or always paying cash at retailers and gas stations, reveal high cash payment shares, high switching thresholds from cash to cards, and high average withdrawal amounts.

Second, we broaden the perspective provided by vKSS. Specifically, we relax their key assumption that cash is the only payment instrument that allows for easy monitoring of spending. Rather, we stipulate that the technological advances in recent years have made card payments similarly attractive in this respect. To this end, we introduce the notion of "digital watchers", i.e. consumers who rely on non-cash payment instruments – debit and credit cards, specifically – to fulfil their monitoring needs. Empirically, we provide evidence that digital watchers' payment behavior is characterized as card-intensive along the aforementioned dimensions, i.e. they behave exactly opposite to pocket watchers (low probability of always paying cash for amounts up to CHF 100 or always paying cash at retailers and gas stations, low cash payment shares, low switching thresholds from cash to cards, and low average withdrawal amounts).

The remainder of the paper is structured as follows. Section 2 briefly summarizes the vKSS framework, describes our extension to digital watchers and formulates the corresponding testable hypotheses. Section 3 describes the survey data underlying our analysis, defines the variables and explains our approach to classify consumers as watchers – pocket or digital. Section 4 compares and discusses consumer group means in the spirit of the mean-comparison tests applied by vKSS. Section 5 presents and discusses reduced-form regression results. Section 6 concludes.

2. Budget control motive

vKSS (2014) develop a theoretical framework stipulating that cash provides consumers with a simple device for minimizing the costs incurred when monitoring their budget, i.e. when keeping track of past expenses and of remaining liquidity.[2] Therefore, cash is of particular use to consumers who display a need to control their budget. Furthermore, consumers who have a relatively high cost of storing and processing information benefit from pocket watching and are thus more likely to adhere to this strategy. Under their assumption that cash is unique in providing

2 In so doing, vKSS complement the literature on payment behavior. Many factors are candidate explanations for the differences in cash usage and the payment-related behavior observed among consumers (see e.g. references in von Kalckreuth et al., 2013). These range from considerations of the relative costs of payment instruments to transaction-specific characteristics and further to deep-seated habits as well as psychological determinants – such as differences in the pain of paying attributable to the payment instrument used.

budget information at a glance, consequently, such consumers use cash more intensively than consumers that are not subject to these constraints.

However, technological progress has led to an increased penetration of the consumer base with online and mobile banking applications, which allow for monitoring available liquidity and past transactions in real-time through electronic devices (such as mobile phones). These developments have eliminated payment cards' disadvantage relative to cash for those consumers who attribute a high value to budget control, as 24/7 access to the liquidity balance on a deposit account and past transactions has become feasible and comparatively easy.

These developments give rise to a straightforward conjecture: We expect that "digital watchers" entered the scene. This is based on the view that the control motive is a fundamental need of those consumers who state it. If technological innovation reduces the relative costs of monitoring through new information channels, consumers may adapt their payment behavior in an effort to minimize their monitoring cost.

In the following, we make use of the vKSS framework to derive testable hypotheses regarding the payment behavior of pocket watchers and digital watchers in terms of cash usage, the number of payment instruments, as well as their switching (from cash to non-cash means of payment) and withdrawal behavior. The hypotheses for pocket watchers are simply a reproduction of those in vKSS. The hypotheses for digital watchers result from generalizing their underlying line of reasoning by dropping their assumption that cash is unique in providing budget information at a glance.

Cash usage: Pocket watchers use cash more intensively than other consumers (i.e. they show a higher probability to use cash only and they conduct a larger share of their payment value and volume with cash). Furthermore, pocket watchers are more likely than other consumers to pay for transactions with a value up to CHF 100 by cash only. The same holds true for transactions at retailers and gas stations. Equivalently, digital watchers use cash less intensively than other consumers. These predictions are driven by increasing monitoring costs for payment instrument watchers with an increasing diversity of payment instrument usage. As a result, payment instrument watchers concentrate their payment activity using their preferred instrument to minimize their monitoring costs.

Number of payment instruments: Pocket watchers use fewer non-cash payment instruments than other consumers, as each additional payment instrument increases monitoring costs. For digital watchers, it is optimal to hold exactly one non-cash instrument. Hence, we would expect digital watchers to use less instruments than other consumers, too. However, as monitoring is conducted via mobile apps for instance, monitoring is not strictly tied to the payment instrument but to the account balance or the transaction records. Rather, the monitoring tool used might allow monitoring several payment instruments simultaneously (for instance, several payment instruments are directly deducted from a consumer's sight deposit account; alternatively, transactions of several payment instruments are charged on the same credit card). Consequently, it is ex ante unclear whether digital watchers hold more or less non-cash payment instruments than other consumers.

Switching behavior: Larger cash holdings are associated with increasing opportunity and shoe leather costs. Hence, also pocket watchers tend to make use of non-cash instruments for higher value payments, if the former costs outweigh the increased cost of monitoring when using cards instead of cash. In contrast, digital watchers have no incentive to use cash and try to minimize the use of cash. Hence, the threshold value that triggers the use of a payment card is higher (smaller) for pocket watchers (digital watchers) than for other consumers that do not associate monitoring costs with their payment instrument usage.

Withdrawal behavior: Pocket watchers exhibit a higher average withdrawal amount and a higher withdrawal threshold[3] than other consumers. The first prediction is related to the minimization of opportunity costs (such as shoe leather costs or the cost of illiquidity) and monitoring costs. While withdrawing too frequently increases shoe leather costs, becoming illiquid is associated either with an opportunity cost of forgone consumption or a higher monitoring cost due to the use of a non-cash payment instrument. Thus, on average pocket watchers withdraw a higher amount than other consumers, as the latter do not have to equilibrate shoe leather costs with monitoring and illiquidity costs. The second prediction is also related to the liquidity argument. Pocket watchers would incur a higher monitoring cost, if forced to switch to card payments in the absence of sufficient cash holdings. Thus, an optimizing pocket watcher holds precautionary cash balances to remain cash-liquid and be able to pay in cash for unforeseen expenses. As digital watchers rely on payment cards to monitor, they withdraw lower average cash amounts and exhibit a lower withdrawal threshold than other consumers. To reduce their monitoring costs, digital watcher would want to reduce their cash holdings to zero. However, digital watchers cannot do completely without cash. For instance, due to the high relative cost incurred by merchants for low-value card payments, merchants often restrict acceptance of non-cash payment instruments (for instance, for low-value payments). Hence, digital watchers still need cash to remain liquid.

3. Data and identification

3.1. SNB survey on payment methods 2017

We use data from a representative survey on the payment behavior and the use of cash by consumers in Switzerland. The Swiss National Bank (SNB) commissioned a

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3 The usual amount of cash left in respondents' wallet that triggers them to refill their pocket via a cash withdrawal.

"Survey on payment methods 2017" that was conducted in autumn 2017. It comprises a personal interview on payment habits and attitudes towards payment instruments and the keeping of a payments diary. Overall, 1968 individuals aged 15 and older were interviewed and provided diaries containing a total of 22'689 recorded transactions.

In the face-to-face interviews, respondents were asked about a broad range of aspects regarding their payment behavior, the underlying motives, their assessment of payment instruments and methods as well as their cash withdrawal behavior. Furthermore, respondents filled in a payment diary, recording information on all (non-recurring) payments over a period of seven consecutive days. Along with other items, the information recorded in the diary encompasses the Swiss franc amount involved, the "place" of payment, the payment instrument used, and whether an alternative payment option would have been available.[4]

The survey reveals that cash is the most common method of payment for consumers in Switzerland. A total of 70% of the transactions were carried out with cash. Those made up for 45% of the total value recorded. The median Swiss consumer possesses two different cashless methods of payment. The dominant non-cash payment instruments are the debit card (90% of respondents own at least one such card) and the credit card (60%). The debit card is by far the most commonly used cashless payment method in Switzerland, accounting for 22% of recorded transactions and 29% of their value. As in other countries, socio-demographic characteristics affect payment behavior to a substantial degree. Specifically, age, income, gender and the language region of residence tend to have a significant bearing on the choice of payment method. Further descriptive statistics are presented in SNB (2018).

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4 Recurring payments (such as rental expenses, insurance premiums, utility bills) were not recorded in detail. Rather, consumers were asked to record these payments in the diary as a one-off total monthly amount.

3.2. Dependent variables

We evaluate the explanatory power of a payment instrument-specific control motive for the heterogeneity in Swiss consumers' intensity of using cash, their switching behavior, their holdings of different payment instruments, and their cash withdrawal behavior.

To evaluate the intensity of using cash, we assess the impact of the control motive on the probabilities that a consumer always pays cash (referred to hereafter as *pays only cash*[5]), never pays cash *(pays only cashless)*, always pays cash for amounts below CHF 100 *(pays always cash up to CHF 100)*, and always pays cash at retailers and gas stations *(pays cash at retail and gas stations)*. Furthermore, we analyze the impact of a payment instrument-related control motive for the share of cash payments in total transactions in terms of volume *(transaction share of cash payments)* and value *(value share of cash payments)*.

When evaluating the number of payment instruments, we consider the number of distinct non-cash payment instruments in possession of the consumer *(# of non-cash instruments in use)*. We approximate switching behavior by the self-assessed value of a transaction that triggers the consumer to switch from cash to card payment *(switching threshold)*. In terms of withdrawal behavior, we analyze the *average withdrawal amount* and the amount of cash in the wallet that triggers a cash withdrawal *(withdrawal trigger amount)*.

To analyze payment instrument usage, we consider only those diary entries for which consumers had a choice of payment instrument; i.e. we calculate transaction and value shares of cash based on those transactions for which consumers had a choice between cash and alternative means of payment at the point of sale. Moreover, to analyze payment instrument usage, switching behavior, payment in-

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5 All variables used are reported in italics.

strument holdings and cash withdrawal behavior, we exclude all consumers who have no choice of payment method, as they do not possess any payment instrument other than cash. These measures reduce the number of transactions entering the calculation of volume and value shares by 9'158 to 13'531 and the sample size by 119 individuals to 1849. Obviously, covariates – for which consumers provided no answers – further reduce the sample.

Above measures help to address the concern that empirical results may be biased due to merchants steering consumers to use certain payment instruments. To limit this effect, we consider payments only for which consumers had a choice of payment instruments. We further argue that for retail transactions and transactions at gas stations merchant steering is not of a great concern.[6] Moreover, merchant steering is rarely associated with a differentiation along the lines of most of our explanatory variables.

3.3. Consumer classification and information processing capabilities

vKSS classify German consumers based on the responses to the payment questionnaire in two distinct ways. The first classification scheme builds on respondents' self-assessed importance of the "pocket watching" strategy. Specifically, it relies on survey questions asking whether consumers consider expenditure control as an indispensable feature of a payment instrument and whether they consider cash as the only means providing it. vKSS denote consumers responding affirmatively to both questions as "pocket watchers". Their second classification relies on

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6 Merchants' loyalty schemes tend to be independent of payment instruments or are linked to credit cards, respectively merchant cards. Given the low penetration of credit or merchant card payments in Switzerland, such merchant steering through loyalty schemes rather strengthens our findings, as statistical relevant differences emerge despite potential credit and merchant card steering. Also, credit card payments and watchers represent the smallest shares in our sample. Watching strategies based on other instruments than cash, debit and credit cards are inexistent.

the determining factors of being a pocket watcher and defines “restricted consumers” as those having both a “need to keep control over their remaining liquidity” and “limited information-processing capabilities”. To designate corresponding individuals, vKSS make use of responses to related questions in the payment survey.[7] Restricted consumers are shown to be more likely to adhere to a pocket watcher strategy and adapt a corresponding payment behavior.[8]

We focus on the importance of “watching”-strategies more generally to explain payment behavior. In so doing, we are able to validate vKSS’ findings for the behavior of “pocket watchers” based on an alternative consumer identification scheme. The availability of this alternative scheme is due to the fact that the Swiss survey asks different questions than the German survey underlying the analysis by vKSS. Going beyond vKSS, the Swiss survey enables us to classify a group of consumers as “digital watchers”, i.e. consumers who value a watching strategy but rely on a non-cash instrument to do so.

Specifically, we group consumers in Switzerland according to the following identification scheme. We rely on a self-assessment of the consumer’s payment type[9] and a self-declared control motive as a reason for why a consumer always or pre-

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7 The “need to keep control over their remaining liquidity” is derived from respondents' answers to the question: “To reach my financial targets, expenditure discipline is very important—unnecessary expenditures have to be avoided.” The “limited information-processing capabilities” is proxied by the average time needed to answer a survey question. Consumers are dichotomized; they are classified as having low information-processing capabilities, if they need more time to answer the survey than the median respondent does.

8 While it would be interesting to replicate findings in relation to restricted consumers, the Swiss questionnaire does not allow to convincingly approximate the “need to keep control over remaining liquidity” for all consumers. However, it is possible to approximate “information processing capabilites” by the interview length as done by vKSS.

9 Respondents were asked to classify their general payment instrument usage strategy among the following five choices: “always cash”, “predominantly cash”, “depending on the situation”, “predominantly non-cash”, “always non-cash”.

dominantly pays with cash or a non-cash payment instrument, respectively.[10] We denote a consumer as *pocket watcher*, if she declares to pay always or predominantly with cash and subsequently mentions a control motive as being among the reasons for doing so.

Correspondingly, we classify a consumer mentioning a control motive as one of the reasons for paying predominantly or always with non-cash instruments as *digital watcher*. We label remaining consumers as *other consumers.*[11] Based on our classification, 18% of consumers are "pocket watchers" and 7% are classified as "digital watchers", while 75% are classified as other consumers. The latter group comprises consumers, who either have no control motive or those who watch their spending through other means such as keeping personal payment diaries. *Table 1* reports key summary statistics of the consumer groups according to our classification.

3.4. Control variables

The literature (von Kalckreuth et al., 2013, vKSS, 2014) and the descriptive statistics outlined in SNB (2018) suggest that individual patterns of using payment instruments are influenced by a broad variety of factors such as socio-demographic characteristics. Hence, adding a number of controls in the reduced form regressions is indispensable.

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10 Respondents with the self-assessed payment type "always cash" or "predominantly cash" were asked for the reasons why they pay always or predominantly in cash. Similarly, respondents with the self-assessed payment type "predominantly non-cash" or "always non-cash" were asked for the reasons why they predominantly or always pay with non-cash instruments. Note, there were no pre-defined answers to these questions, i.e. responses to these questions were not limited to a set of options and no particular options were offered to consider. A control motive is identified, if the answer matches the meaning of "I use cash / non-cash instruments, as I believe cash / non-cash instruments allow me to control my expenditures".

11 Other consumers encompass all payment types (i.e. consumers who pay always and predominantly with cash or with non-cash payment instruments as well as consumers who characterize their payment instrument choice as situation-dependent). Other consumers may have a control motive, too. However, their monitoring activity is not associated with the use of a payment instrument (but may involve a diary or other ways of monitoring) and remains unknown.

Consumer groups: Demographic descriptive statistics Table 1

	Full sample	Pocket watcher	Digital watcher	Other consumer
Age	46.11	47.79	41.25	46.16
	[16.85]	[18.15]	[15.25]	[16.59]
Household income	2.56	2.11	2.77	2.64
	[1.35]	[1.17]	[1.43]	[1.36]
Education	2.11	2.00	2.17	2.13
	[0.56]	[0.54]	[0.56]	[0.57]
Female	0.51	0.48	0.52	0.52
	[0.50]	[0.50]	[0.50]	[0.50]
Observations	**1849**	**328**	**129**	**1392**

Notes:
"Age" is reported in years.
"Household income" is reported in five bins: 1 denotes monthly income of less than CHF 4'000, 2 denotes income between CHF 4'000 and 5'999, 3 denotes income between CHF 6'000 and 7'999, 4 denotes income between CHF 8'000 and 9'999, and 5 denotes income of CHF 10'000 and more. The table reports the group-wise averages of these ranges.
"Education" is divided into three categories: 1 denotes compulsory education (primary school, lower secondary level, or no education), 2 denotes upper secondary education (high school, vocational high school, grammar school), and 3 tertiary education (university of applied sciences, higher technical school, university etc.). The table reports the group-wise averages of these categories.
"Female" denotes the share of female respondents in the respective consumer groups.
Values in brackets denote standard deviations.

We control for the following socio-demographic characteristics: *age, income, education,* gender *(female relative to male)*, the language region of residence[12] (*German-* or *French-speaking Switzerland relative to Italian-speaking Switzerland*), and the *degree of urbanization* of the municipality of residence.

12 Descriptive statistics indicate substantial differences in payment instrument usage among residents in the three dominant language regions of Switzerland; see SNB (2018).

We further control for the relative costs of payment instruments by means of six different variables: 1) We consider the consumer's own assessment of the cost of cash relative to non-cash payment instruments *(relative cost assessment (cash vs non-cash))*. Specifically, we define this variable as the difference between the cost of cash and the least costly card instrument. The relative cost results from the consumer's responses to questions on how she assesses her cost of paying with cash, the debit and the credit card on a predefined ordinal scale. 2) The *average transaction value* is understood to decrease the relative cost of card payments. 3) As a first proxy of shoe leather cost, we include a dummy variable that takes the value 1, if a consumer is commuting *(commuter).*[13] 4) As a second proxy of shoe leather cost, we include *municipality size*. 5) We further control for the consumer's own assessment of the importance of anonymity *(anonymity important)*. 6) We consider security risk. Consumers were asked to report their assessment of the security risk of each payment instrument. The variable considered is defined as the difference between the security risk assessment of cash and the security risk assessment of the card payment instrument with the highest/best value (*relative security risk assessment (cash vs non-cash))*.

When assessing withdrawal behavior, we further control for the cash amount in the consumer's wallet at the beginning of the payment diary *(cash in wallet start of diary)* as well as the cash amount in the wallet at the end of the payment diary *(cash in wallet end of diary)*. This is relevant as we derive the average withdrawal amount from a seven-day payment diary. The average withdrawal amount is thus sensitive to idiosyncratic cash holdings at the start and the end of the diary.

In the empirical analysis, we tackle the hypotheses regarding the payment behavior

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13 The idea being here, that commuters have lower shoe leather cost, as they pass by train stations and thus city centers, i.e. locations where ATMs are typically situated. As a result, commuters do not have to make a particular effort to go to an ATM.

of pocket and digital watchers, applying two complementary empirical strategies. First, we compare group means of pocket watchers, digital (debit and credit card) watchers and other consumers for all payment and withdrawal behavior variables under scrutiny. Second, we conduct reduced-form regression analysis to validate that differences found in the descriptive part are not simply due to the heterogeneity in covariates.

4. Descriptive evidence

In this section, we compare the payment and withdrawal behavior of our different consumer groups based on mean comparisons.

Table 2 summarizes the results of the comparison of the mean behavior of pocket watchers, non-cash watchers and other consumers. In columns (I) to (III), it shows the group means for each payment and withdrawal variable and provides in columns (IV) to (VI) the respective p-values of the test for the null of equal group means (Satterthwaite-Welch-test for equality of mean). We find that payment behavior of pocket watchers differs significantly from the corresponding behavior of digital watchers and other consumers.

Cash usage: As predicted by the extended vKSS framework, pocket watchers (digital watchers) use cash statistically significantly more (less) intensively than other consumers. Substantially more pocket watchers than other consumers only use cash. Vice versa, substantially more digital watchers than other consumers only use non-cash payment instruments. Both value- and transactions-based cash shares differ from each other. Pocket watchers use cash most intensively, followed by other consumers. Digital watcher exhibit the least intensive cash usage. The same observation holds true for the two indicators on whether a person always pays cash for payments below CHF 100 and on whether a person always pays cash at retailers and gas stations.

Switching amount: Consumer groups are statistically significantly different from each other with respect to their switching amount. The switching amount of pocket watchers is by far the largest with almost CHF 210. Other consumers' average switching amount is reduced to almost CHF 75 and digital watchers show a much lower witching amount with less than CHF 30.

Watching and payment behavior: Mean comparison among consumer groups Table 2

		(I) Pocket watcher	(II) Digital watcher	(III) Other consumer	(IV) p-value I vs II	(V) p-value I vs III	(VI) p-value II vs III
Cash usage	Pays only cash	0.36	0.00	0.11	0.00	0.00	0.00
	Pays only cashless	0.00	0.09	0.02	0.00	0.00	0.01
	Value share of cash payments	0.83	0.40	0.58	0.00	0.00	0.00
	Transaction share of cash payments	0.88	0.49	0.67	0.00	0.00	0.00
	Pays always cash up to CHF 100	0.55	0.02	0.19	0.00	0.00	0.00
	Pays cash at retail and gas stations	0.60	0.06	0.26	0.00	0.00	0.00
Switching threshold	Amount at which person starts paying with cards	209.70	27.07	74.89	0.00	0.00	0.00
Payment instruments	# of non-cash instruments in use	1.90	2.78	2.32	0.00	0.00	0.00
Withdrawal behavior	Average withdrawal amount	225.37	105.32	160.45	0.00	0.05	0.00
	Withdrawal trigger amount	49.45	27.12	44.30	0.00	0.23	0.00

Notes:
For detailed description of variables and consumer groups, see sections 3.2 to 3.4.
Identification scheme: Self-declared watching strategy.
P-values derived based on Satterthwaite-Welch-test for equality of mean.

Instrument number: As expected, pocket watchers show the lowest number of payment instruments. Somewhat surprisingly, digital watchers go with the largest number of payment instruments. However, as explained above, this may not necessarily interfere with their watching strategy. All differences are statistically significant.

Withdrawal behavior: The mean comparison reveals a pattern in line with the theoretical predictions. In terms of the average withdrawal amount, pocket watchers withdraw the largest amount with CHF 225 on average, whereas other consumers withdraw an average amount of CHF 160, and digital watchers withdraw an average amount of CHF 105. All these numbers differ statistically significantly. In terms of the trigger amount, pocket watchers show an average trigger amount of CHF 49, other consumers one of CHF 44, and digital watchers one of CHF 27. Interestingly, the difference between pocket watchers and other consumers is statistically insignificant. This suggests that other consumers also have a relatively strong preference for cash liquidity.

Overall, our findings support the framework by vKSS as well as the integration of digital watchers into their framework. Importantly, however, differences in the means could be related to covariates such as socio-demographic factors and other potential determinants of payment instrument choices. To assess the role of a control motive more formally, we therefore explicitly control for such factors in the following reduced-form regressions.

5. Reduced-form equation analysis

Analogously to the descriptive evidence in Section 4, we estimate reduced-form behavioral equations for each dependent variable. Whenever dependent variables are dummy variables, we use binary probit. For probit regressions *Table 3* shows marginal effects. For one dependent variable – the number of payment instruments in use – we use multinomial ordered probit. Focusing on whether consumers are expected to hold more or less payment instruments, *Table 3* shows coefficient estimates (we report corresponding threshold parameters in tables). For all other variables, we use OLS.

Overall, the results confirm the theoretical predictions. Furthermore, but without going into detail, controls are in line with intuition and the findings by vKSS and related literature as well as the descriptive evidence provided in the survey by the SNB (2018). In the following discussion of the results, we focus on our variables of main interest – the pocket watchers and digital watcher. In doing so, we refer to the numbering of regression as provided in *Table 3* (columns (I)-(X)).

Cash usage: In relation to cash usage, results show that pocket watchers and digital watcher differ statistically significant from other consumer. Pocket watchers (digital watchers) use cash significantly more (less) intensively than other consumers do. Statistically, all results are highly significant.

Pocket watchers are much more likely than other consumers to use only cash (I), to use only cash for amounts up to CHF 100 (II) and to use only cash at retail or gas stations (III). Furthermore, their cash shares in terms of value (IV) and volume (V) are higher than the corresponding shares of other consumers. Vice versa, the opposite holds for digital watchers. For instance, they are significantly more likely to use exclusively non-cash payment instruments (VI).

Instrument number: Pocket watchers (digital watchers) use less (more) payment instruments than other consumers (VII). Results are strongly significant. All threshold parameters of the ordered probit regression turn out to be statistically significant as well.

Switching amount: Pocket watchers (digital watchers) indeed show a statistically significant higher (lower) switching amount than other consumers (VIII).

Withdrawal behavior: Pocket watchers and digital watchers also differ in terms of their withdrawal behavior. Considering the average withdrawal amount (IX), pocket watchers (digital watchers) withdraw higher (smaller) average amounts than other consumers. Results are highly statistically significant. The withdrawal trigger amount of digital watchers is statistically indistinguishable from the one of other consumers.[14] In contrast, the withdrawal threshold (X) of pocket watchers is statistically significantly higher than the one of other consumers. To summarize, whereas digital watchers and other consumers seem to have a similar disutility from illiquidity, pocket watchers still have a statistically significantly stronger preference to stay cash-liquid than digital watchers.

6. Conclusion

vKSS (2014) provide a theoretical framework stipulating that cash usage is higher among individuals who display a need to control their budget and/or with restricted information processing capabilities, based on the assumption that cash is particularly well suited to monitor liquidity and past expenses. We extend the theoretical framework by vKSS to allow for other payment instruments than cash to provide these monitoring features as well.

We find evidence that is consistent with the predictions derived from this generalized framework: Both so-called pocket and digital watchers show a payment behavior that is characterized as intensive in their respective watching instrument, i.e. either in cash or in debit and credit cards.

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14 This is the only notably difference to the unconditional mean comparison analysis. Thus, the significant difference between digital watchers and other consumers can already be explained by other covariates. In particular, digital watchers are younger, make on average lower average payments, and evaluate cash worse relative to cashless instruments compared to other consumers. These factors by themselves already imply a lower withdrawal trigger amount, so that taking into account these factors, there is no marginal contribution of being a pocket watcher for withdrawal behavior.

More specifically, based on consumer survey data from Switzerland we find that cash users who have a budget control motive exhibit a payment behavior consistent with pocket watching, thereby validating the results of vKSS.

Relaxing the assumption by vKSS that cash is the only payment instrument capable of providing monitoring efficiently, we show that other payment instrument watchers exhibit patterns of payment behavior that are consistent with the extended vKSS framework. Technological innovation seems to have facilitated timely budget and payment information acquisition. This allows consumers, which we denote as "digital watchers", to fulfil their monitoring needs by other tools (such as mobile banking or credit card apps) that are tied to cashless payment instruments. In particular, our empirical analysis indicates that digital watchers meet their monitoring need by means of card payments and, consequently, to show a card-intense payment behavior.

Cash and non-cash instruments differ in terms of how strongly payment and monitoring are tied together. Only cash serves as both payment and monitoring instrument at the same time. This implies a stronger link between payment and monitoring in the case of cash, whereas monitoring based on cashless payment instruments is a bit more removed. It requires, at least as of today, both a tool to monitor (e.g. mobile banking app) and a cashless payment instrument linked to that tool (e.g. debit or credit card). The difference might have implications for the medium- to long-term success of a monitoring strategy and might influence cash usage correspondingly. The results of this study, however, do not speak to the question of how successful the different watching strategies are, for example, for the propensity to consume, budget overview and budget control. These questions are left for future research that will further improve our understanding of current and future cash usage.

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Watching and payment behavior: regression analysis

Dependent variable:	(I)	(II)	(III)	(IV)
	Pays only cash	**Pays always cash up to CHF 100**	**Pays cash at retail and gas stations**	**Value share of cash payments**
Method:	Probit	Probit	Probit	LS
Pocket watcher	0.117***	0.253***	0.255***	0.223***
	[0.017]	[0.030]	[0.034]	[0.026]
Digital watcher		-0.309***	-0.253***	-0.161***
		[0.097]	[0.075]	[0.037]
Household income	-0.018***	-0.020*	-0.027**	-0.036***
	[0.007]	[0.010]	[0.011]	[0.008]
Education	-0.037***	-0.082***	-0.040	-0.052***
	[0.014]	[0.024]	[0.026]	[0.018]
Age	0.004	0.005	-0.002	-0.006
	[0.003]	[0.004]	[0.005]	[0.003]
Age, squared	-0.000006***	-0.000011***	0.000049***	0.0001***
	[0.000025]	[0.000042]	[0.000048]	[0.0000]
Female	-0.053***	-0.109***	-0.073***	-0.045***
	[0.015]	[0.024]	[0.027]	[0.019]
Degree of urbanization	0.005	0.028	0.015	0.019
	[0.012]	[0.019]	[0.022]	[0.016]
German-speaking Switzerland	-0.006	0.047	0.040	0.097***
	[0.019]	[0.033]	[0.037]	[0.026]
French-speaking Switzerland	-0.009	0.018	0.031	0.057**
	[0.021]	[0.038]	[0.041]	[0.029]

Table 3.1

(V)	(VI)	(VII)	(VIII)	(IX)	(X)
Transaction share of cash payments	**Pays only cashless**	**# of non-cash instruments in use**	**Switching threshold**	**Average withdrawal amount**	**Withdrawal trigger amount**
LS	Probit	Ordered Probit	LS	LS	LS
0.182*** [0.022]		-0.372*** [0.088]	0.960*** [0.132]	0.182*** [0.064]	0.290*** [0.104]
-0.178*** [0.031]	0.015** [0.007]	0.294*** [0.120]	-0.720*** [0.178]	-0.358*** [0.100]	0.002 [0.145]
-0.026*** [0.007]	0.000 [0.002]	0.122*** [0.026]	0.016 [0.039]	0.028 [0.020]	0.060* [0.031]
-0.049*** [0.015]	0.005 [0.005]	0.198*** [0.060]	-0.178** [0.090]	-0.047 [0.045]	0.004 [0.073]
-0.003 [0.003]	0.000 [0.001]	0.043*** [0.011]	0.027 [0.017]	0.011 [0.008]	0.020 [0.014]
0.000046 [0.000029]	-0.000005 [0.000011]	-0.0005*** [0.0001]	0 [0.0002]	-0.0001 [0.0001]	0.0001 [0.0001]
-0.026 [0.016]	0.001 [0.005]	-0.127*** [0.063]	-0.004 [0.095]	0.044 [0.048]	-0.198*** [0.076]
0.024* [0.013]	-0.003 [0.004]	-0.022 [0.052]	0.109 [0.078]	-0.031 [0.039]	-0.026 [0.063]
0.025 [0.022]	-0.002 [0.007]	0.243*** [0.087]	-0.611*** [0.133]	0.228*** [0.066]	-0.381*** [0.106]
0.020 [0.024]	-0.002 [0.007]	0.054 [0.098]	-0.400*** [0.148]	0.194*** [0.075]	-0.808*** [0.118]

Watching and payment behavior: regression analysis

	(I)	(II)	(III)	(IV)
Dependent variable:	**Pays only cash**	**Pays always cash up to CHF 100**	**Pays cash at retail and gas stations**	**Value share of cash payments**
Method:	Probit	Probit	Probit	LS
Relative cost assessment (cash vs non-cash)	0.003 [0.005]	0.004 [0.009]	0.033*** [0.010]	0.020*** [0.007]
Average payment value	-0.010 [0.010]	0.055*** [0.018]	-0.037* [0.020]	-0.091*** [0.014]
Commuter	-0.001 [0.015]	0.002 [0.025]	0.014 [0.028]	0.007 [0.020]
Size of municipality	0.006 [0.006]	0.005 [0.010]	-0.001 [0.011]	0.004 [0.008]
Anonymity important	-0.021 [0.024]	0.020 [0.039]	-0.008 [0.045]	0.045 [0.033]
Relative security risk assessment (cash vs non-cash)	0.023*** [0.004]	0.027*** [0.007]	0.027*** [0.007]	0.016*** [0.005]
Cash in wallet, start of diary				
Cash in wallet, end of diary				
Constant	-0.241** [0.097]	-0.467*** [0.157]	-0.036 [0.174]	1.024*** [0.123]

Table 3.2

(V)	(VI)	(VII)	(VIII)	(IX)	(X)
Transaction share of cash payments	**Pays only cashless**	**# of non-cash instruments in use**	**Switching threshold**	**Average withdrawal amount**	**Withdrawal trigger amount**
LS	Probit	Ordered Probit	LS	LS	LS
0.015** [0.006]	-0.003* [0.002]	-0.018 [0.024]	0.058 [0.036]	-0.010 [0.018]	-0.025 [0.030]
-0.076*** [0.011]	0.002 [0.003]	0.062 [0.046]	0.160** [0.067]	0.327*** [0.036]	0.250*** [0.055]
0.007 [0.017]	0.002 [0.005]	-0.080 [0.066]	-0.269*** [0.099]	0.071 [0.050]	-0.098 [0.079]
0.009 [0.006]	-0.003 [0.002]	0.005 [0.026]	0.015 [0.039]	-0.010 [0.020]	0.027 [0.031]
0.043 [0.028]		0.158 [0.110]	0.478*** [0.168]	-0.040 [0.083]	0.376*** [0.132]
0.015*** [0.004]	-0.004*** [0.001]	-0.048*** [0.017]	0.108*** [0.026]	0.024* [0.013]	0.076*** [0.020]
				0.009 [0.026]	
				0.263*** [0.022]	
0.979*** [0.104]	-0.037 [0.033]		2.230*** [0.618]	2.192*** [0.321]	1.289*** [0.493]

Watching and payment behavior: regression analysis

Dependent variable:	(I) Pays only cash	(II) Pays always cash up to CHF 100	(III) Pays cash at retail and gas stations	(IV) Value share of cash payments
Method:	Probit	Probit	Probit	LS
Limit_2				
Limit_3				
Limit_4				
Limit_5				
Limit_6				
Limit_7				
Observations:	1193	1193	1176	1193
R-squared:	0.253	0.195	0.143	0.216
F-statistic:	NA	NA	NA	20.198

Notes: For detailed description of variables and consumer groups, see sections 3.2 to 3.4.
Values in brackets denote standard errors. ***, **, * denote significance at the 1%, 5%, 10% level, respectively.
Probit estimates report marginal effects at the mean.

Table 3.3

(V)	(VI)	(VII)	(VIII)	(IX)	(X)
Transaction share of cash payments	**Pays only cashless**	**# of non-cash instruments in use**	**Switching threshold**	**Average withdrawal amount**	**Withdrawal trigger amount**
LS	Probit	Ordered Probit	LS	LS	LS
		0.863** [0.415]			
		1.933*** [0.417]			
		2.830*** [0.420]			
		3.483*** [0.423]			
		4.064*** [0.431]			
		4.956*** [0.504]			
1193	1193	1193	1085	852	1053
0.219	0.150	0.055	0.220	0.366	0.229
20.604	NA	NA	18.777	26.659	19.250

Janina Harasim, Monika Klimontowicz
What could induce Polish consumers to reduce cash payments?

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Abstract

Using new data from a 2018 survey conducted on a representative sample of Polish consumers, we assess how product price, speed, ease of use and security of payment method influence consumers' decisions to use cash or non-cash payments. We also examine which incentives (financial incentives, material bonuses or tax benefits) could change their payment habits.

We apply different statistical methods, such as Thurstone's method of paired comparisons for the analysis of preferences, association (co-occurrence) analysis for exploring payment patterns, and correlation analysis.

The results show that a lower product price has a more significant impact on the choice of payment method than payment instrument attributes such as speed, convenience and security. We also found that consumers are more receptive to monetary incentives (like discounts) than material bonuses or tax benefits. We dis-

covered the statistically significant correlation between the kind of incentive and a consumer's socio-demographic characteristics.

The research results have practical implications for merchants, public authorities and banks (including central banks) in terms of the choice of incentives used to change customers' payment habits. It should increase the effectiveness of the increasing initiatives that aim to reduce the use of cash and drive greater adoption of non-cash payments.

1. Introduction

Despite the dynamic development of non-cash payments and payment innovations which could become an alternative to cash, especially in low-value payments, the use of cash for payments in many countries is not falling. Poland is one of such countries where the share of cash in all payments is still relatively high. Concurrently, what may be surprising is that Poland is thought to be one of the leaders in payment innovations such as contactless cards, and mobile and online payments, not only compared to other European countries, but worldwide.

Generally, the demand for cash can be driven by two factors–treating cash as a store-of-value and/or a means of payment. This paper refers to research on the transactional function of cash (cash as a means of payment). It aims to find the answer to the research question: What payment instrument attributes and what kind of incentives may induce Polish customers to switch from cash to non-cash payments? The structure of the paper is as follows. Section II presents the importance of cash in Poland. Section III summarizes the relevant literature on factors determining the choice of payment method, including payment instrument attributes and incentives that encourage customers to change their payment patterns. Section IV contains the results of consumers' assessment of payment method attributes. Section V presents respondents' attitudes towards cash and shows how the product price, as well as speed, convenience and security of payment method influence their decisions to use cash or noncash payments. In this section, we also analyze which incentives could induce consumers to reduce cash payments. The last part of the paper includes the research findings.

2. The importance of cash in Poland

To measure the importance of cash in the economy, two approaches can be used:

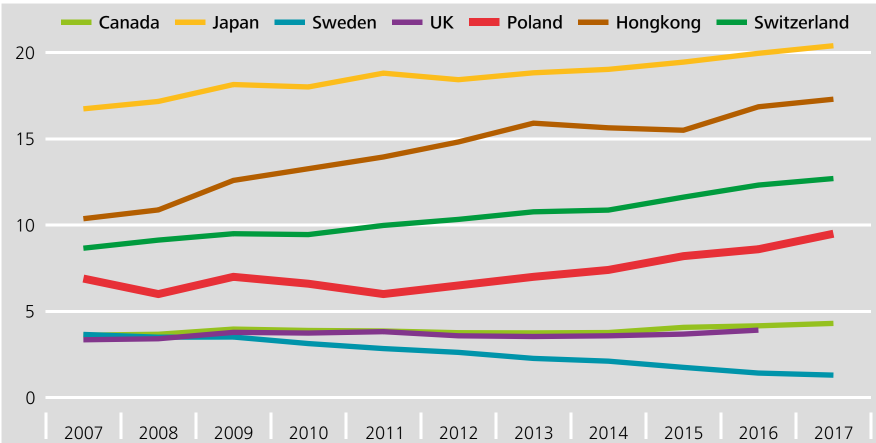
- static (a stock measure), where the cash in circulation as a percentage of GDP (currency-to-GDP ratio) is considered,
- dynamic (a flow measure), where the use of cash for payments is taken into account.

Obviously, the cash (i.e. banknotes and coins) in circulation (scaled by GDP) is not equivalent to the use of cash for payments. However, since comparable cross-country data on cash usage is not available, the cash in circulation is frequently used as a proxy for cash demand [Amromin and Chakravorti, 2007; Williams and Wang, 2017; Bech et al., 2018]. Since 2004, the currency-to-GDP ratio in Poland has increased more than half from 6% to 9.5% in 2017. Within this period, the currency-to-GDP ratio fell twice–in 2008 and in 2010-2011. In 2011, the currency-to-GDP ratio reached the 2004 level, and since then has been increasing dynamically at a rate of 0.4-0.9 p.p. per year. Data published by the Committee on Payments and Market Infrastructures (CPMI) of the Bank for International Settlement in Basel (Red Book statistics) shows that in most of the countries included in the CPMI statistics[1], similarly to Poland, the cash in circulation has increased since 2007. Poland is situated in the middle, between countries characterized by a lower level of ratio such as Sweden, Great Britain, Canada and Brazil, and countries where the share of cash in GDP is significantly higher, for example, Japan, Korea or Switzerland (*Figure 1*).

1 The 24 countries included in the CPMI statistics are: AU, BE, BR, CA, CN, EA, FR, DE, HK, IN, IT, JP, KR, MX, NL, RU, SA, SG, ZA, SE, CH, TR, GB and US.

Cash in circulation as a percentage of GDP

Figure 1



Source: CPMI-Red Book statistics, 2007 – 2017

The second measure enabling the assessment of the use of cash for payments is usually based on research using a payment diary method. Such surveys are generally conducted by central banks using their own methodology (this differs slightly from country to country) and usually are of domestic reach. One of the first surveys based on a large sample of countries was carried out for the ECB by Kantar Public (Brussels) in 2016. The survey, conducted in 17 Eurozone countries, was divided into three waves from October 2015 to July 2016, except for Germany and the Netherlands[2]. The total sample for the Eurozone–including data from Germany and the Netherlands–was of 92,080 respondents, reporting

2 In Germany and the Netherlands, the corresponding central banks have been carrying out similar payment diary surveys since 2008 and 2007 respectively. The latest available survey results from these countries are from 2014 for Germany and 2016 for the Netherlands. The central banks in these countries preferred to continue using their own methodology in order to avoid deviating from their historical results. Nevertheless, to the extent possible, the results of these two countries have been integrated with ECB data to present the results for the whole Eurozone.

a total of 198,600 payments. In most countries, they wrote down all payments made during a single day, only Cyprus and Malta used a three-day diary.

The highest share of cash in total payments was registered in Malta (92%), Greece (88%) and Spain (87%), while the lowest was in the Netherlands and Finland–45% and 54% respectively [Esselink, Hernandez 2017].

The data for Poland (*Figure 2*) was collected during National Bank of Poland (NBP) research on banking and payment service usage by Polish citizens using a different methodology [Koźliński, 2017][3]. However, both the EBC and NBP studies show the percentage share of cash payments in total payments made at points of sale (POS) in 2016. The result for Poland (63%)[4] is lower than the Eurozone mean (79%).

The decreasing propensity of Polish consumers to use cash was revealed by D. Maison's research conducted for NBP in 2009, 2013 and 2016 [Maison 2017]. Research shows that the percentage of people preferring cash had dropped sharply between 2009 and 2016 (from 64% in 2009, to 49% in 2013, and to 39% in 2016), but cash is still preferred in low-value transactions[5].

These changes result undoubtedly from the rapid spread of contactless cards, which are the main alternative to cash in low-value transactions made at POS. In 2015, Poland was still one of the countries characterized by a low level of payment card usage (less than 75 transactions per inhabitant) and an average level of con-

---

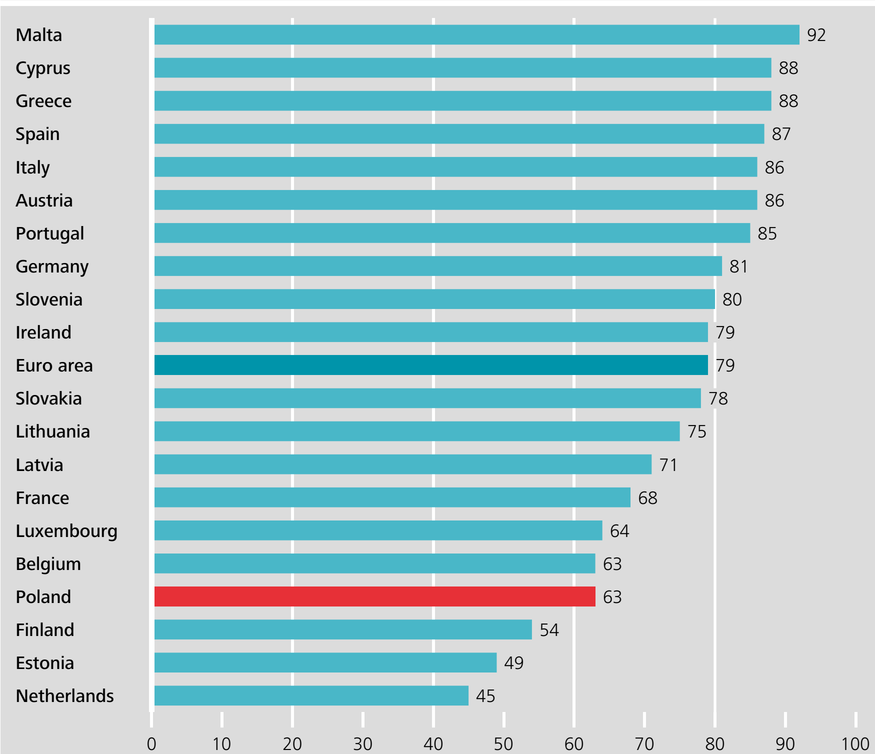
3 It was carried out in 2016 on a representative sample of 970 adults using CAPI methodology (Computer Assisted Personal Interview).
4 In September 2017, the results of research using two methodologies (questionnaire and payment diary method) were published. The report "Badanie czynników oddziałujących na wielkość obrotu gotówkowego w poszczególnych regionach Polski" (Research on factors influencing cash circulation in particular regions of Poland) [NBP 2017] showed that cash was used in 53.92% of transactions.
5 In 2016, for the first time cards were chosen more frequently than cash in transactions of 11-50 PLN, while cash remained the dominant payment instrument for transactions below 10 PLN.

tactless card usage (the share of contactless transactions in the total number of transactions varies between 10% and 50%)–see *Figure 3*.

Since 2009, the number of contactless cards in Poland increased from 0.3 to 34.8 million in 2018 (*Figure 4*). This growth was accompanied by an increase in the number of POS terminals accepting contactless payments (*Figure 5*).

Share of cash transactions per country at points of sale Figure 2

%



Source: Esselink H., Hernández, L. 2017

Country clusters for contactless payments

Figure 3

		Card payment usage*		
		LOW transaction penetration <75	MEDIUM transaction penetration 75-150	HIGH transaction penetration >150
Contactless payment usage**	VERY LOW <3%	Bulgaria Cyprus Germany Greece Italy Lithuania Malta Romania Slovenia	Belgium Latvia Portugal	Denmark Estonia Finland Luxembourg Norway Sweden
	LOW 3-9%	Austria Croatia Spain	France Ireland	The Netherlands
	MEDIUM 10-50%	Hungary Poland Slovakia		United Kingdom
	HIGH >50%	Czech Republic		

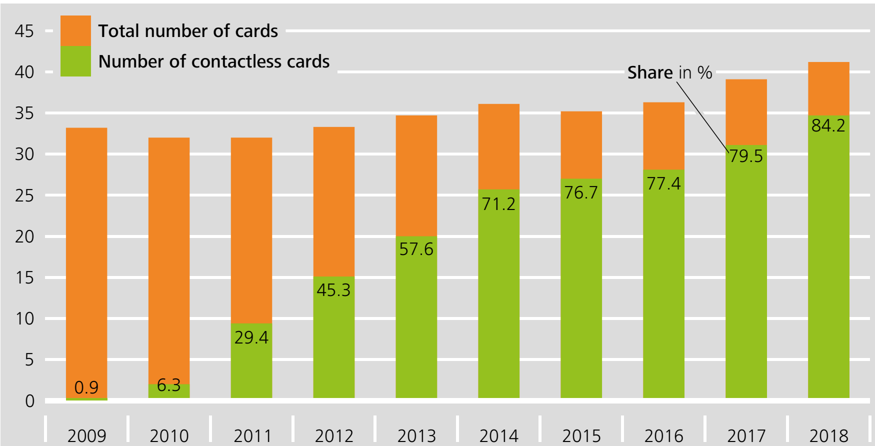
** Transaction penetration - the number of card transactions per capita per year*
*** Contactless penetration - the total amount of contactless transactions versus the total amount of face to face card transactions*

Developed	These markets are pioneering the payment innovation and the consumer adoption of contactless payments is massive. It is driving a consistent increase in the total number of cardbased transactions.
In development	Consumer adoption of contactless payments is often mainly concentrated in metropolitan areas. It is driving a noticeable increase in the total number of card-based transactions.
Movers	Consumer adoption of contactless payments is increasing fast and is driving a consistent increase in the total number of card-based transactions.
Slow movers	The introduction of contactless solutions has not been recognised yet as a factor for further development of consumer payment behaviour.
Last movers	The introduction of contactless solutions might be a factor for further development of consumer payment behaviour and number of card-based transactions.

Number of contactless cards issued in 2009 – 2018

Figure 4

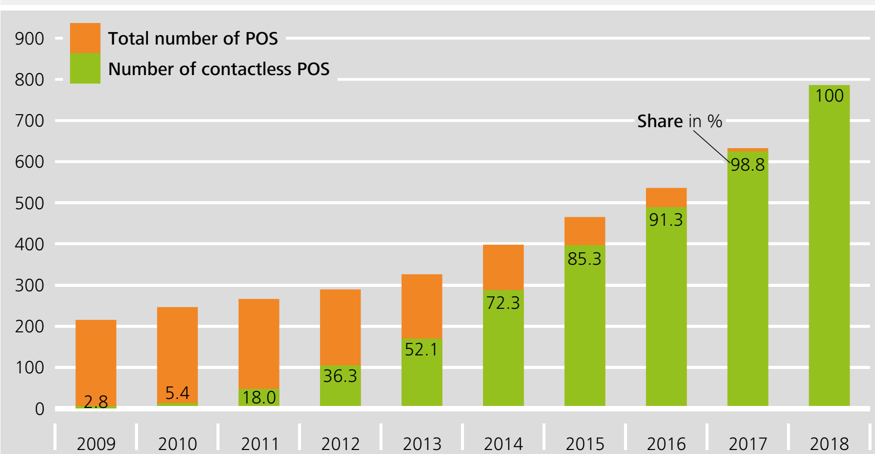
million



Number of contactless POS in 2009 – 2018

Figure 5

thousand



As a result of such a spectacular development of contactless cards, Poland has become one of the leading contactless payments markets for not only in Europe but even in the world. According to the latest NBP data, at the end of the first quarter 2019, the number of contactless cards reached 35 million and their share in the total number of cards issued increased to 84.8% [NBP, 2019]. At the same time, the number of POS terminals reached 822,000 and for the first time in history, all of them accepted contactless payments [NBP, 2019].

In spite of the fast development of contactless cards, a large number of Polish people still prefer to use cash in daily transactions. Over half of them pay in cash habitually. This means that there is the significant room for reducing the use of cash for payments in Poland, and it demonstrates than research on this topic is needed.

3. Literature review

Although explaining the real drivers of consumer payment choices is not easy work due to several supply-side and demand-side factors affecting it, there exists both theoretical and empirical literature that addresses this problem. Most previous research focused on two payment instruments: cash and cards. Some early research also took into consideration checks [Bounie and François, 2006]. The research carried out in recent years also took into account innovative payment instruments such as contactless cards, mobile payments and online payments [Chen, 2008; Pousttchi, 2008; Schierz, Schilke, Wirtz, 2010; Shaw, 2014]. All such research generally explains how consumers pay and which factors affect their payment choices. Fewer studies try to answer the question: What should be done to encourage consumers to switch from cash to non-cash payments, i.e. to change their payment patterns?

One of the first research studies conducted by Kennickell and Kwast [1997] showed that both the difference in the cost of cash versus debit card and the necessity to hold a suitable amount/reserve of cash are factors which encourage customers to choose non-cash payments. The significant importance of cost in the process of cash substitution was also stressed by Huphrey, Kim and Vale [2001] as well as Borzekowski, Kiser and Ahmed [2008]. They found that bank-imposed fees may negatively affect the use of debit cards at the point of sale. In turn, Zinman [2009] stated that the cost of relying on credit cards influences consumers' choice between credit and debit cards. Research conducted in the first decade of the 21st century concluded that consumer payment choice depends to a large extent on the so-called transactional context, i.e. transaction size, type of goods and services purchased, and place of transaction [Hayashi and Klee, 2003; Bounie and François, 2006; Jonker, 2007; Klee, 2008; Von Kalckreuth et al., 2009; Mester, 2012]. For example, Bounie and François [2006] showed that cash was used mostly in low-value payments, and that card usage increased with the value of the transaction. This relationship was confirmed by further research including studies conducted in Poland [Maison 2010, 2017; Koźliński, 2013]. In other research carried out in the same decade, sociodemographic factors (age, education, income, gender etc.) were analyzed as determinants of payment behavior [Stavins, 2001; Klee, 2006; Borzekowski and Kiser, 2008; Zinman 2009]. These studies generally showed that demographics and income (or household assets) could be good predictors of the preferences for different payment instruments. The results proved the negative correlation between age and the usage of electronic payments, and showed that such payments are preferred by well-educated and high-income consumers. In some studies, the relationship between consumer payment behavior and attributes of the payment instrument such as cost, security, speed and convenience were analyzed. Most of the studies analyzing the cost of payments (i.e. the cost of acquiring and using various payment methods) did so by taking into consideration cash and cards (especially credit cards) [Humphrey, Kim, and Vale, 2001; De Grauwe, Rinaldi, and Van Cayseele, 2006; Klee, 2008; Zinman 2009]. Research showing how perceptions of security affect payment behavior are rather limited. In models of consumer payment behavior, the assessment of security has been found to significantly affect payment use, although the effect is not as large as the effect of cost or convenience assessment [Stavins, 2013; Koulayev et al., 2016]. Besides of cost and security, nowadays there is more and more evidence that speed and convenience significantly affect consumers' payment choices [Klee, 2006; Borzekowski and Kiser, 2008; Arango, Huynh and Sabetti, 2011; Schuh and Stavins, 2015].

Cash usage was analyzed more in depth by Meijer [2010], Bagnal et al. [2016] and in Poland by Maison [2010, 2017]. Meijer stated that although European countries are tending to substitute cash with electronic payments, cash will not be totally eliminated as it is anonymous, tangible, immediately available and the cost of its usage is perceived by customers as close to zero. He also pointed out that many people prefer using cash for historical reasons. Cash is available to all members of society including the poor, most minors and the financially excluded. Bagnall et al. [2016] analyzed consumers' use of cash in seven countries in Europe, North America and Australia. They found that the share of cash transactions remain high in all the countries analyzed, especially for low-value transactions. In all the countries studied, the use of cash was strongly correlated with demographics (such as income or education), transaction size, and point-of-sale characteristics (such as merchant card acceptance and venue).

Most previous studies on the choice of payment instruments were based on aggregate consumer or household surveys offering limited information on attitudes towards cards and cash, and no information on the role of incentive-related mechanisms. There are two basic incentives which could accelerate the substitution of cash with non-cash payments (especially cards): merchant-imposed discounts and/or surcharges, and reward or loyalty programs connected with credit cards. It must be stressed that in many countries, applying a surcharge was or is legally restricted, and is limited by numerous constraints[6]. As a

6 In the European Union, the Payment Services Directive 2007/64/EC explicitly states that merchants

result, many merchants rarely use it. For this reason, if they decided to differentiate prices based on the method of payment, they rather chose discounts on cash or debit card transactions than surcharges. Most surveys on price incentives were conducted in the United States in the first decade of the 21st century. Amromin, Jankowski, and Porter [2007] analyzed toll payments on the Illinois Tollway and discovered that consumers rapidly switched to electronic payments when toll fees doubled for cash payers. In 2010, using consumer and retailer survey data from the Netherlands (where both cash discounts and card surcharges are legal), Bolt, Jonker and van Renselaar [2010] showed that about 22 per cent of Dutch retailers practiced card surcharges, while no retailers in their sample practiced cash discounts. They also proved that high surcharges on debit card transactions do steer Dutch consumers away from debit cards to cash. In turn, Shy and Stavins [2015] stated that despite U.S. merchants' recent freedom[7], they rarely decided to differentiate prices based on the method of payment. The survey results found that the prevalence of discounts and surcharges based on payment method had not increased from 2012 to 2015. The theoretical reasons for merchants' reluctance to offer them was the subject of a paper by Briglevics and Shy [2014].

Most studies on the role of rewards programs were undertaken from a behavioral perspective and showed significantly large and positive effects of incentive programs (reward points, discounts, and cash-back) for general purchases [Hsee et al., 2003]. But none of them examined in particular the role of incentive programs in

can surcharge and/or offer a discount for the use of a given payment instrument. However, Member States were authorized to prohibit or limit surcharging on their territory. A survey of surcharging practices conducted in 2012 by the European Commission showed that surcharging is an expanding practice, and the countries with the highest share of surcharging merchants were Ireland (15 percent), the United Kingdom (14 percent), and the Netherlands (10 percent). From December 2015, in conjunction with an MIF Regulation, interchange fees for credit and debit cards issued and used in Europe were capped, and surcharging and discounting were prohibited on payment instruments that are subject to this Regulation (such as Visa and MasterCard).

7 In the US, merchants have been allowed to surcharge certain credit card transactions in order to recover their credit card processing costs since January 27, 2013. Surcharging is nonetheless still prohibited on any debit card or pre-paid card transactions.

card payments. In the banking literature, Gross and Souleles [2002] stated that consumers' preferences towards cards are not linear and they may vary considerably when contractual conditions (such as interest rates, repayment schemes or rewards programs) change. Furthermore, using a unique survey of consumers' preferences for payment instruments in Spain, Carbó-Valverde and Liñares-Zegarra [2009] showed that rewards programs can significantly affect the preferences for cards relative to cash payments, and that the effects of these rewards vary significantly among merchant sectors. The reported impact of rewards on card usage was higher for debit card holders than for credit card holders. Similarly, Ching and Hayashi [2010] found that payment card rewards had statistically significant effects on consumer choice of payment methods. Arango, Hyunh, and Sabetti [2011] also tried to assess how reward program incentives and merchant acceptance affect consumer payment choice. The results suggested that in mature card payment markets like Canada, card users are quite inflexible with regard to variations in incentives. However, the probability of using a credit card increases with transaction value due to the proportionality of credit card reward plans. In the U.S., Stavins and Wu [2017] found that the occurrence of price incentives was low, but that consumers were significantly more likely to switch to using cash because of cash discounts offered, even after controlling for transaction value and merchant type. Other studies also confirmed that reward programs can steer consumers toward greater card usage [Agarwal, Chakravorti, and Lunn, 2010; Simon, Smith, and West, 2010].

In Poland, surveys on cash and non-cash payments, as well as on customer attitudes to particular payment methods, are being conducted more and more frequently. Despite this, the data on individual consumer transactions is still rather limited. In most surveys carried out so far, CAPI, CAWI or PAPI methodology was applied, while in a very limited number of them the payment diary method was used [Koźliński, 2013; NBP, 2017]. The results allowed for an estimate of the share of cash in retail payments, as well as the scope of its usage taking into account transaction size, place, product/service type and consumer demographics. So while the research conducted so far help to explain how Polish consumers pay, less attention has been paid to explaining why they pay as they do. So far, cash has also been rarely compared with other payment instruments in terms of cost, security, speed and convenience. Futhermore just a few studies have focused on customers' propensity to change current payment habits. One of the first such studies was conducted by Harasim in 2013. The results showed that cash is perceived by customers as the cheapest and simplest payment method. Innovative payment methods turned out to be the fastest, but over 40% of respondents could not imagine replacing cash with innovative payment methods in the nearest future [Harasim 2015]. Since this research had a regional reach, extrapolating the results for the whole population was not possible. As the study presented in this paper was carried out on a representative sample of Polish customers, its results have more comprehensive character.

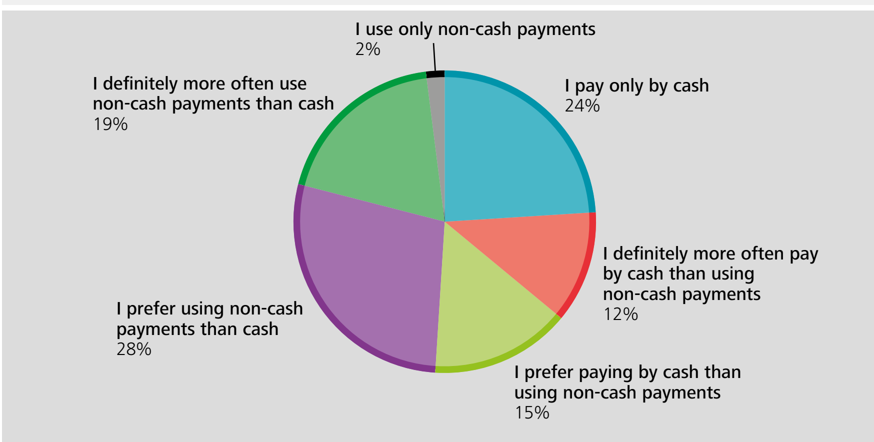
4. Assessment of payment method attributes

The data analyzed in this paper was collected during a survey conducted by IPSOS in February and March 2018 using a questionnaire prepared by Harasim and Świecka. The survey sample was representative of Polish consumers over 15 years old. Altogether, 1100 questionnaire-based interviews were conducted using the CAPI method (Computer-Assisted Personal Interview). The representativeness of the data gathered was assured by rim weighting to adjust the sample to the structure of the Polish population in terms of gender, age and the level of education RIM-weighting method was used. The scope of the research included the following issues: the use of cash and non-cash payments and the reasons for using them; incentives which can induce customers towards greater use of non-cash payments; assessment of payment instruments being an alternative for cash in terms of speed, convenience, security and cost; and assessment of the financial knowledge and skills of respondents in the field of payments.

The first part of the research focused on the preferred payment methods. The results showed that every fourth respondent uses only cash. The next 27% of respondents definitely more often used cash. Although 47% of respondents used non-cash payments definitely more or rather likely, only 2% declared that they use only non-cash payments (*Figure 6*).

To determine the willingness to switch from cash to non-cash payments, we selected consumers who prefer cash over non-cash payments and we focused on the cash-competitive payment instruments perceived as the most important substitutes for cash in POS transactions i.e. contactless cards and mobile proximity payments [Harasim 2016, p. 55]. Using a non-parametric Chi-squared test of independence, assuming a statistical significance of p=0.05, we checked if the respondents' payment patterns depend on age, gender, education level and place of residence. The results showed a statistically important relationship between the form of payment and age, level of education and place of residence. There is no correlation between the form of payment and gender (*Table 1*).

The use of cash and non-cash payments in Poland in 2018 Figure 6



Source: Harasim, Świecka 2018

The relationship between preferred payment method and sample features

Table 1

The sample features	p-value for chi2 test
gender	p=.516
age	p=.000
level of education	p=.000
place of residence	p=.015

Respondents who always or are definitely more likely to choose cash are people over 60 years old living in rural areas, with a primary education, and who in the vast majority of cases lived very economically or are forced to limit their spending.

Among the respondents who rather prefer non-cash payments were predominantly people aged 25-39. The percentage of people living in large cities in this group was more than double compared with those who prefer cash, and the percentage of those who were highly-educated was three times greater. Their economic situation was also much better. Although more of them live economically, more than one-third declared that they can afford everything, and the percentage of those who had to limit their spending was two and a half times lower compared with respondents who preferred cash.

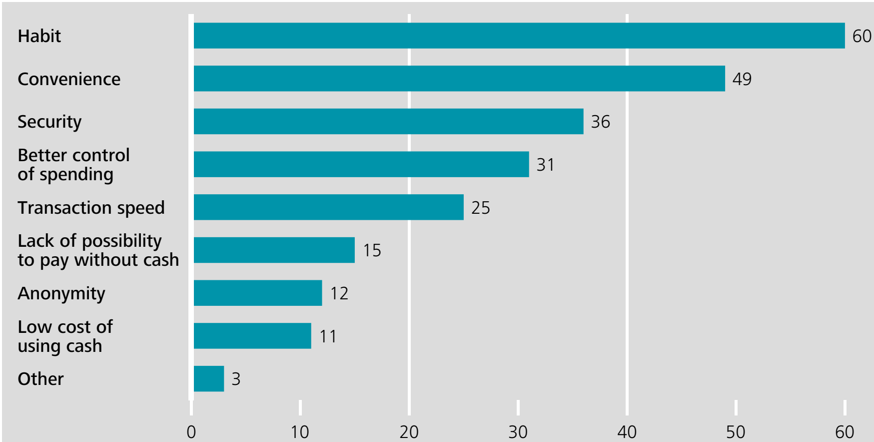
We also found that people who prefer paying in cash do it habitually and/or because it is convenient. Over one third of respondents considers cash payments as safe and enabling control over spending. One fourth chose cash because of speed (*Figure 7*).

The frequency of using cash depends on the type of transaction (in POS or online), the transaction size and the place of transaction/ kind of goods and services purchased. Respondents prefer paying in cash in low-value transactions made at POS. Cash is

The reasons for preferring cash as a payment method

Figure 7

%



Source: Harasim, Świecka 2018.
Notes: Responders were allowed to choose three answers. That is why the results do not sum up to 100%.

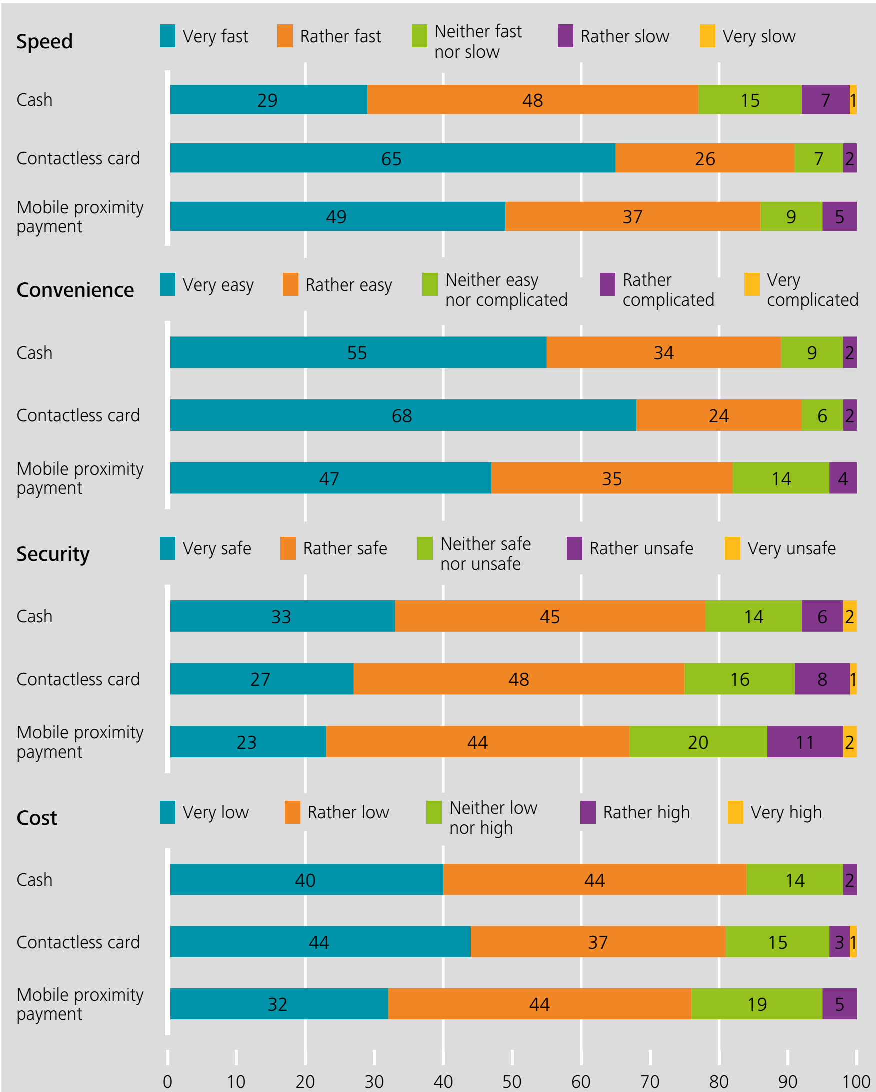
rather not chosen for purchases made online and for purchases of durable goods. Consumers willingly pay in cash for services, food and other consumer goods as well as in public administration offices. One-third of respondents use cash for paying bills.

Generally, paying in cash results from customers' preferences, but respondents quite often pointed out the lack of possibility to pay without cash, which means that the level of merchant acceptance of alternatives to cash is insufficient. For over one-third of respondents, it was a barrier to paying for services, and for one fourth in public administration offices. About one-fifth of respondents use cash because they do not have a bank account or card. Even consumers preferring non-cash payments use cash in low-value payments and when transaction speed is a priority.

Consumers' assessment of payment method attributes

Figure 8

%



Source: Harasim, Świecka 2018

The respondents were also asked to assess the attributes of particular payment instruments used in transactions made at POS, which are the area where cash dominates. The respondents assessed attributes such as speed, ease of use (convenience), security and cost using a 5-point Likert scale. *Figure 8* presents the results.

Surprisingly, security was the only attribute of cash assessed higher in comparison with other payment instruments. Most respondents thought cash to be convenient, but the convenience of using contactless cards was graded higher. Contactless cards were assessed as the fastest payment method in in-person transactions. In terms of speed, cash was listed as the last. Despite the fact that the use of cash is perceived as a payment method that is free of charge, most respondents assessed the cost of using the contactless card as lower than cash. The results prove that contactless cards are perceived by Polish consumers as a real alternative to cash and, despite some concerns regarding safety, they have a huge potential to replace cash in daily transactions. The most probable fields for such substitutions are everyday payments for goods and services as well as payments in public administration offices.

5. Consumers' attitudes towards cash and their sensitivity to incentive-related mechanisms

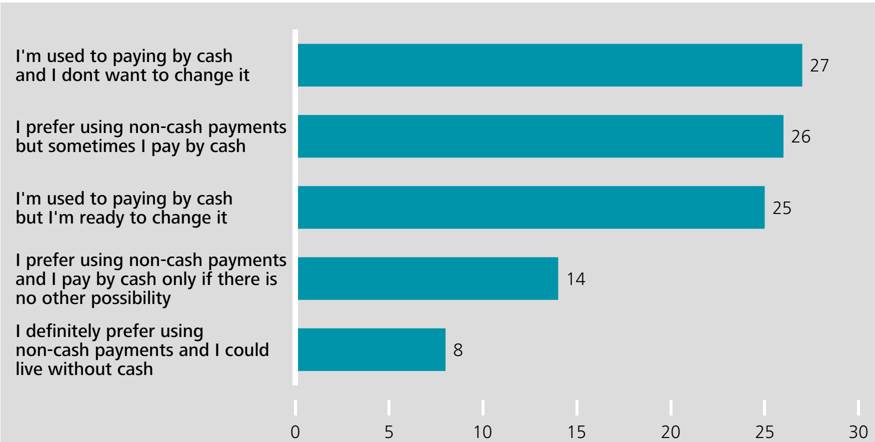
Despite the increasing willingness to use non-cash payments, as many as 27% of respondents do not intend to give up cash payments, and only 8% of respondents thought that living without cash is possible (*Figure 9*).

Regardless of the respondents' attitude to cash, the dependency on age, gender, education level and place of residence were checked by a non-parametric Chi-squared test of independence, assuming a statistical significance of p=0.05 (*Table 2*). Similarly, as for payment preferences, respondents who prefer paying in cash and did not want to change this are people over 60 years old living in rural areas

The attitudes towards using cash

Figure 9

%



Source: Harasim, Świecka 2018

The relationship between the attitude toward cash and sample features

Table 2

Sample features	p-value for chi2 test
gender	p=.340
age	p=.000
level of education	p=.000
place of residence	p=.000

who are relatively less well-educated. The majority of those who did not share this opinion may be described by the statement: I prefer using non-cash payments but I sometimes use cash (for example for making small purchases).

However the main research goal was not only to find out how consumers make their payment choices, but also why they pay as they do, and what may convince them to reduce their use of cash. Such studies are justified since 69% of respondents who often or very often pay in cash chose that method even if non-cash payments were accepted. Almost half (47%) of them behave like this in the case of low-value transactions, 14% did it because they think card payments take more time, and 6% pointed out both reasons. Respondents also declared that they pay in cash as they used to do it or are finacially excluded (due to the lack of bank account and/or card).

To establish what incentives may convince respondents to change their payment patterns, the Thurstone comparative assessment method was applied[8]. The method makes it possible to build a one-dimensional metric preference scale based on data on preferences obtained using the pairwise comparison scale. A ranking scale of non-cash payment reasons was used, in which respondents ranked 4 types of non-cash payment reasons on a ranking scale, where rating 1 meant the most preferred reason and 4 the least preferred (*Table 3*).

8 Method details can be found in Thurstone [1927]. See also Tsukida and Gupta [2011].

Ranking options for preferred reasons for using non-cash payments

Table 3

Options	Description
1	If the price of goods/services is lower for the non-cash payment.
2	If the transaction speed is higher for the non-cash payment.
3	If the non-cash payment is as (or more) convenient than a cash payment.
4	If the non-cash payment is more secure than the cash payment

The frequency of placing a particular option in different positions (%)

Table 4

	Option 1	Option 2	Option 3	Option 4
1st position	41.36	25.64	14.91	18.09
2nd position	16.82	19.64	22.91	17.82
3rd position	11.09	20.36	17.27	19.91
4th position	11.73	14.91	20.73	19.55

The frequency of placing particular options in different positions (from 1 to 4) is presented in *Table 4*. Option 1 was most often chosen in first position (41%), and option 3 in second position (23%). Data in the form of a ranking scale was then processed into the results of pairwise comparisons of individual objects. On the basis of comparative assessments, a table of proportions was created in which a given reason is preferred over another–the results are shown in *Table 5*.

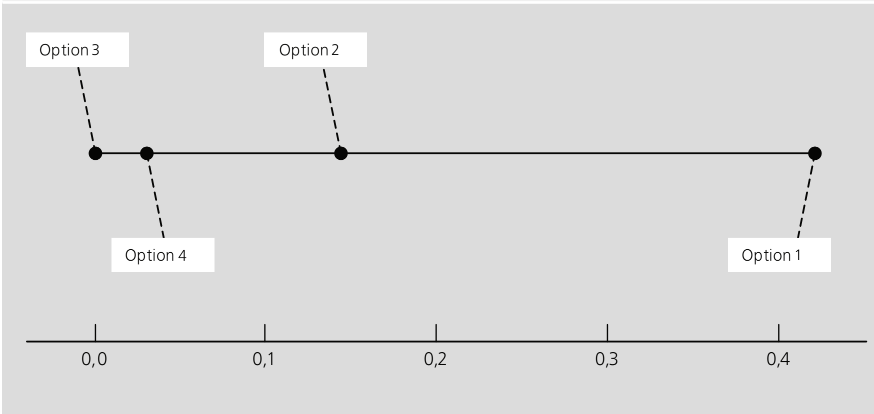
The calculations show that the first option (lower price) is more important for 62% of respondents than the second option (speed). The second option is more important than the third (convenience) for 55% of respondents, and 51% of respond-

The proportions of respondents preferring one option over each of the others

Table 5

	Option 1	Option 2	Option 3	Option 4
Option 1	0.00	0.38	0.34	0.35
Option 2	0.62	0.00	0.44	0.45
Option 3	0.66	0.56	0.00	0.51
Option 4	0.65	0.55	0.49	0.00

The scale of options' comparative assessment Figure 10



ents recognize the fourth option (security) as more important than the third. In the final stage of the analysis, a graphical interval one-dimensional scale of comparative assessments was created (*Figure 10*).

The highest sensitivity to price incentives was confirmed in the further part of the research. The respondents were asked what kind of incentives could encourage them to switch from cash to non-cash payments. Almost 60% of them, having the possibility to chose only one incentive, decided to choose financial benefits (monetary rewards). 21% of respondents chose tax benefits, and 18% material bonuses. A non-parametric Chi-squared test of independence showed a statistically important relationship between the benefit preferences and the place of residence and age (p=.009). All groups of respondents pointed out financial benefits as the most important, but the group of the elderly over 60 years old was less sensitive. In the case of tax benefits, the less sensitive group was the group aged 15-24, and for material bonuses respondents aged 40-59.

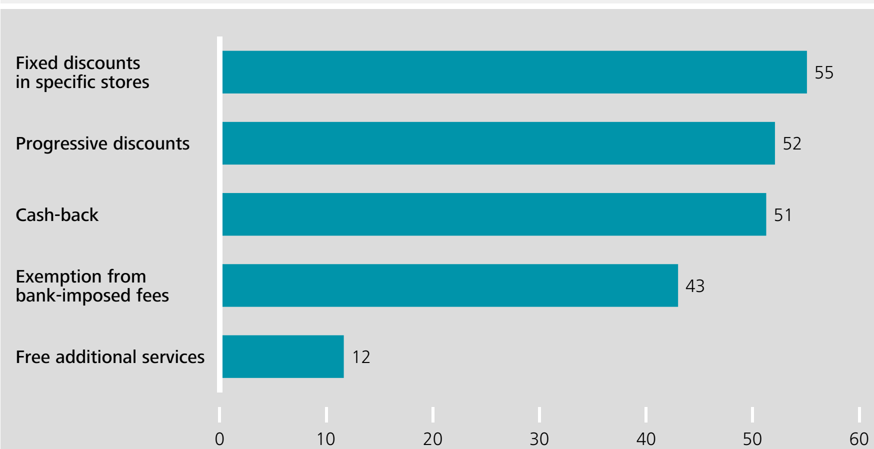
Considering that monetary rewards had been preceived as the most important, they were analyzed further. Each respondent could choose three from the following benefits:

- exemption from fees (for an account, card, etc.)
- fixed discounts in specific stores (regardless of the volume of purchases)
- progressive discounts (increasing with the size of expenses)
- cash-back (repayment of a part of non-cash paid expenses)
- points exchanged for prizes, additional discounts, etc.
- free additional services in shopping centers, cinemas, restaurants, hotels or airports

55.1 % of respondents chose fixed discounts in specific stores, while slightly more than half chose progressive discounts or cash-back. (*Figure 11*).

Financial benefits preferred by respondents Figure 11

%



Source: Harasim, Świecka 2018

Association (co-occurrence) analysis was used to discover interesting relationships between the different kinds of financial incentives chosen by consumers. These relationships are represented in the form of a set of frequent items or association rules (e.g. fixed discounts, progressive discounts). The strength of an association rule can be measured in terms of its support and confidence. The first measure used in this paper determines how often a rule is applicable to a given data set. In order to discover the most frequent item sets, the Apriori algorithm is adopted [Hastie et al., 2001]. The same method used to extract all high-support rules between the financial benefits that would convince a consumer to use non-cash payments.

Analysis of the results showed that over 12% of respondents chose three advantages while the rest chose only two. Almost one third chose one of the forms of price reduction: fixed discounts, progressives discounts or cash-back. (*Table 6*).

The most frequently chosen combinations of incentives Table 6

The most popular combinations of financial incentives	Number of respondents	Percentage
Fixed discounts + progressive discounts	310	28.18
Fixed discounts + cash-back	295	26.82
Cash-back + progressive discounts	294	26.73
Cash-back + the exemption from fees	220	20.00
Progressive discounts + the exemption from fees	218	19.82
Fixed discounts + the exemption from fees	205	18.64
Fixed discounts + cash-back + progressive discounts	136	12.36

6. Conclusions

Despite the fact that Poland is one of the leading countries in the adoption of payment innovations (especially for contactless cards), the share of cash in transactions made at POS is still large. This is why we wanted to discover why Polish consumers prefer paying in cash, and how cost, speed, convenience and security of the payment method/instrument affect consumers' payment choices.

The results showed that those who pay in cash do it habitually or because they prefer paying like this. The assessment of payment method attributes showed that cash is highly valued than non-cash payments only in terms of security. In terms of convenience and cost, contactless cards received the highest grades, and in terms of the transaction speed, cash was listed as the last. Such an assessment proves that on the rational level, Polish consumers have already realized that contactless cards might be a good alternative for cash in daily transactions, but that emotional factors, mainly habits, make cash still the preferred means of payment used for in-person transactions. As a result, over one-fourth of respondents does not intend to give up paying in cash.

Analysis of the incentives which could induce ‘cash-lovers’ to switch from cash to non-cash payments proved that respondents are much more sensitive to financial incentives, especially different kinds of price reduction (i.e. fixed or progressives discounts, cash-back etc.). They are less interested in indirect financial incentives such as a reduction in or exemption from bank-imposed fees and charges, and much less interested in tax benefits or material bonuses.

Most previously conducted research, especially that carried out using payment diary methodology, had focused on how consumers make their payment choices. The research results presented in this paper are far-reaching as they help to explain why consumers pay as they do and what should be done to induce them to change their payment patterns. Additionally, contrary to other studies, we conducted more in-depth analysis of the payment behavior of consumers who prefer cash, and we identified the main cash-competitive payment methods which may be used in POS transactions i.e. contactless cards and mobile proximity payments. To our best knowledge, our research is the first in Poland to analyze customer sensitivity to different types of incentives aimed at encouraging them to switch from cash to non-cash payments. Since the study used a survey method, i.e. we analyzed customers' declared willingness to change their payment patterns and not real behavior, it would be beneficial to conduct further research using the diary method or retailer data to assess the real scope of applied incentives and their efficiency in the process of changing customer payment patterns.

The research results have practical implications for merchants, public authorities and banks (including central banks) concerning the choice of incentives used to change customer payment habits. It should increase the effectiveness of the ever more numerous initiatives aimed at reducing the use of cash in order to drive greater adoption of non-cash payments.

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Shaun O’Brien
Changes in U.S. Consumer Payments: A Study of the Diary of Consumer Payment Choice

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Abstract

Consumer payment usage in the U.S. has been changing for several years and the latest 2018 Diary of Consumer Payment Choice study found cash was used for 26 percent of payments while debit and credit accounted for 28 percent and 23 percent, respectively. This was the lowest share of cash use reported since the Diary studies began in 2012, represents a 5 percentage point decline from the 2016 share, and marks the first time participants reported greater debit card usage than cash. The change in cash use is, ultimately, due to two main reasons: people are using cash less often, either because 1) they want to or 2) because they have to. Changing cash usage habits can be attributed to changing preferences, changing

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shopping habits, or a shift in one's financial status from unbanked/underbanked to banked. Transactions requiring individuals to use less cash include online shopping and in-person transactions where cash is not accepted.

This paper examines whether individuals are more likely to reduce their cash usage because of a shift in preferences and habits or are the result of market forces. Payment data from 1,883 individuals who have participated in the Diary since 2016 was analyzed to understand how banking status, online shopping, cash acceptance, and place of residence influenced cash use over three years. The largest single factor affecting change in cash use is a change in one's payment preference, wherein individuals who initially preferred cash, now prefer cards. This switch in preference changes the probability of using cash at any given price point. In addition, the change in preference is toward cards shows consumers continue to prefer to make payments with established payment instruments.

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Cash Product Office

As the nation's central bank, the Federal Reserve ensures that cash is available when and where it is needed, including in times of crisis and business disruption, by providing FedCash® Services to depository institutions and, through them, to the general public. In fulfilling this role, the Fed's primary responsibility is to maintain public confidence in the integrity and availability of U.S. currency.

The Federal Reserve System's Cash Product Office (CPO) provides strategic leadership for this key function by formulating and implementing service level policies, operational guidance, and technology strategies for U.S. currency and coin services provided by Federal Reserve Banks nationally and internationally. In addition to guiding policies and procedures, the CPO establishes budget guidance for FedCash® Services, provides support for Federal Reserve currency and coin inventory management, and supports business continuity planning at the supply chain level. It also conducts market research and works directly with financial institutions and retailers to analyze trends in cash usage.

1. Introduction

Between 2016 and 2018 participants in the Diary of Consumer Payment Choice reported using cash less often, with the average adult using cash for approximately 14 payments per month in 2016, 12 payments in 2017, and 11 payments in 2018. While the share and number of cash transactions has declined since 2016, there has been no fundamental change in the market that affects the price consumers face when paying with cash, debit cards, or credit cards, nor has there been a significant change in the price of acquiring cash. Despite this consistent pricing in the payments market, consumers, in aggregate, have shifted their payment usage away from cash. While the number of payment options available to consumers is greater now than ever before, the vast majority of payments, particularly non-bill payments, are still conducted using either cash, debit, or credit.

There have been numerous studies looking at how transaction value, demographic characteristics, merchant type, payment adoption, and homing influence payment choice. Stavins (2017) provides a detailed review on these topics. Previous research has explored the correlation between payment choice at the point of sale and the total value of the purchase. A significant body of literature from around the world of studies utilizing diary type data collection, including work by Klee (2008), Cohan and Rysman (2013), Briglevics and Schuh (2016), Koulayev (2016), Wang and Wolman (2016), Wakamori and Welte (2017) have all shown a negative correlation between cash use and transaction amount, wherein as the transaction amount increases the likelihood of cash use decreases. Studies that include demographic information have found a correlation with household income, education, and race with payment use, where those with lower household incomes, younger, or less education are more likely to use cash [Carow and Staten (1999), Rysman (2007) Connolly and Stavins (2015), Koulayev (2016), Schuh and Stavins (2010, 2013, 2015), Stavins (2013, 2016)].

Wang and Wolman (2016) use transactional level data over a three year period and predict the decline in cash usage, especially for smaller value payments, which has been observed in recent Diary studies through the CPO. Other factors influencing cash use include card acceptance, ratings on payment characteristics, and individual payment preferences. Wakamori and Welte (2017) use the Bank of Canada's Method of Payments Study, which contains a combination of transaction and survey data, to conduct a simulation assuming supply side factors are no longer a limitation for card use and estimate a decline in cash use if card acceptance expands. However, the magnitude of this decline suggests that consumers use cash even in the absence of supply side restrictions. Connolly and Stavins (2015) also find that payment instrument use over time evolves rather slowly, which may also explain why cash continues to be used frequently by consumers. Koulayev (2016), Schuh and Stavins (2010, 2013, 2015), Stavins (2013, 2016) described how the characteristics of payment instruments affect both payment adoption and use. An additional finding from Stavins (2016) shows that payment characteristics greatly improve model fit when estimating adoption, but play a far less important role when estimating payment instrument use.

In addition to payment instrument characteristics and demographics influencing payment instrument choice, an important factor is an individual's payment instrument preference and whether or not that individual "homes" on that instrument. Rysman (2007) and Shy (2013) both find evidence of homing on payment cards, with O'Brien (2014), and van der Cruijsen, Hernandez, and Jonker (2017) finding similar results when including both cash and cards.

This paper expands upon previous research by showing how the ratings provided by individuals for each payment's characteristics, not just adoption or usage, explain why individuals prefer to use one payment instrument over another. The results show that much of the decline in cash use is the result of changing payment preferences which are in turn driven by changes in consumer's perceived cost and convenience of debit and credit cards, which in line with van der Cruijsen, Hernandez, and Jonker (2017) . However, what specific mechanism is driving this shift in preference remains unknown. The paper utilizes a panel data set in which 1,883 individuals participated in three consecutive Diaries starting in 2016. This data structure allows one to study how year-to-year variations in socioeconomic variables and assessments of payment characteristics determines one's payment preferences and, in turn, the likelihood of an individual using cash.

The remainder of this paper is organized as follows. Section 2 describes the Diary of Consumer Payment Choice and summary statistics comparing the panel data used in this study with the full set of yearly Diary participants. Section 3 describes the methodology of payment preference decisions as well as payment choice at the point of sale. Section 4 describes the results and Section 5 concludes the findings.

2. Data

2.1 Diary of Consumer Payment Choice

The Diary of Consumer Payment Choice (the Diary) is an annual survey of US Consumers that has been done each year since 2015. As described in Greene, Schuh, and O'Brien (2016), individuals who participated in the Diary starting in 2015 were selected from a different sampling frame than those selected for the 2012 Diary. In 2015, most participants were drawn from the University of Southern California's Understanding America Study (UAS) panel. At that time, the number of individuals able to participate from the UAS would have greatly reduced the typical population size of approximately 2,800 individuals and additional participants from the GFK Knowledge

Panel were included in the 2015 study.[2] Beginning in 2016, all Diary participants were selected from the UAS panel. Also of note, the 2015 Diary was the only study that did not take place throughout the month of October. Instead, the 2015 Diary began in mid-October and continued through mid-December.[3] The difference in panel composition as well as the change in timing of the 2015 Diary makes comparison of the 2015 Diary to the more recent Diary studies problematic. Given this fact, this paper uses the three most recent Diary studies, 2016, 2017, and 2018.

A key benefit of drawing from the same UAS panel year after year is the large number of repeat participants. Since 2016, 1,883 individuals have participated for three consecutive years. This allows researchers to see how the same group of individuals change their payment behavior from one year to the next. While there are benefits of having a sub-sample of the Diary participants repeat year after year, it does present a concern related to reporter bias, as the demographic characteristics of those that select to participate over multiple years may vary from those who choose not to participate repeatedly. Because of this risk for selection bias, the next section compares the 2016 to 2018 panel (referred to as the panel from now on) to the full set of Diary participants starting in 2016.

2.2 Comparing the Full Sample and the Panel

While the panel was not selected to be a nationally representative sample, which is the case for the full sample, the year-to-year population differences between the two groups are quite minor. One important factor for the similarity is that repeat diarists make up a majority of each year's respective diary population. *Table 1a* below shows demographic summary statistics of the full Diary and panel samples from 2016 to

2 While most participants were from the UAS panel, to increase the number of individuals who participated in the 2015 Diary, approximately 300 individuals from GFK Knowledge Panel were also included. Additionally, some individuals from UAS were asked to take the diary twice in an effort to increase observations.

3 See Greene, O'Brien, and Schuh (2017) for additional details

2018 and *Table 1b* shows socioeconomic composition for each group over the last three years. There are few year to year differences between the two populations. Of the 2,848 individuals who participated in the 2016 Diary, 1,883 repeated the Diary for the next two years. Of the remaining 965 individuals, 343 repeated the Diary only in 2017, 201 repeated the Diary only in 2018, and 421 only took the Diary once in 2016.

Demographic Comparison of All Diary Participants and the Diary Panel in 2018 Table 1a

Age	**2016**	**Panel in 2016**	**2017**	**Panel in 2017**	**2018**	**Panel in 2018**
Under 25	6%	6%	5%	5%	5%	4%
25 to 34	23%	23%	25%	24%	25%	24%
35 to 44	17%	15%	16%	17%	16%	16%
45 to 54	17%	19%	17%	18%	17%	17%
55 to 64	17%	19%	17%	18%	17%	18%
65 and Older	20%	19%	20%	18%	21%	21%
Race/Ethnicity	**2016**	**Panel in 2016**	**2017**	**Panel in 2017**	**2018**	**Panel in 2018**
Black	13%	-	14%	-	15%	14%
Other	7%	-	6%	-	7%	7%
White	81%	-	80%	-	79%	81%**
Hispanic or Latino	12%	-	12%	-	12%	12%
Education	**2016**	**Panel in 2016**	**2017**	**Panel in 2017**	**2018**	**Panel in 2018**
Less Than High School	7%	7%	7%	6%	7%	7%
High School	33%	34%	33%	32%	32%	34%
Some College	29%	27%	28%	27%	28%	27%
College	17%	17%	18%	19%	18%	17%
Post Graduate	14%	14%	14%	15%	14%	14%
N	2,848		2,793		2,873	1,883

The composition of the full Diary sample from each year and the panel indicate no obvious selection bias based upon observable demographic characteristics. While there are some variations from one year to the next that were statistically different (White in 2018 and those making less than $25,000 in 2017), the vast majority of these differences are not statistically significant.

Demographic Comparison of All Diary Participants and the Diary Panel Table 1b

Household Income	2016	Panel in 2016	2017	Panel in 2017	2018	Panel in 2018
Less than $25,000	21%	21%	17%	15%**	22%	21%
$25,000 – $49,999	23%	24%	23%	23%	18%	18%
$50,000 – $74,999	17%	17%	20%	20%	18%	17%
$75,000 – $99,999	12%	12%	13%	14%	13%	14%
$100,000 – $124,999	11%	11%	10%	11%	11%	11%
Greater than $125,000	15%	15%	16%	17%	19%	19%
Employment Status	**2016**	**Panel in 2016**	**2017**	**Panel in 2017**	**2018**	**Panel in 2018**
Employed	64%	64%	63%	63%	62%	62%
Unemployed	7%	7%	7%	7%	6%	6%
Disabled	9%	9%	8%	8%	9%	9%
Retired	19%	19%	19%	19%	20%	20%
Banking Status	**2016**	**Panel in 2016**	**2017**	**Panel in 2017**	**2018**	**Panel in 2018**
Unbanked	8%	8%	8%	7%	9%	8%
Banked	92%	92%	92%	93%	91%	92%
N	2,848	1,883	2,793	1,883	2,873	1,883

*Indicates difference is significant at alpha = 0.10
**Indicates difference is significant at alpha = 0.05

When looking at the number of cash, debit, and credit payments, just as with the observable demographic and socioeconomic characteristics, the differences between the two groups suggests the panel is similar to each full year sample with the number of payments by instrument being largely statistically equivalent. The largest difference for the number of cash and debit card payments took place in

Average Number of Monthly Payments by Payment Instrument - 2016 to 2018 Diary Panel Table 2

Year	Cash		Credit		Debit	
2016	14.7		9.4**		12.1	
95% CI	13.9	15.5	8.7	10.1	11.2	12.9
2017	12.4		8.8		10.3	
95% CI	11.5	13.2	8.0	9.6	9.3	11.2
2018	11.3		9.8		11.7	
95% CI	10.4	12.2	8.9	10.7	10.5	12.6

*Indicates difference is significant at alpha = 0.10
**Indicates difference is significant at alpha = 0.05

Average Number of Monthly Payments by Payment Instrument - 2016 to 2018 Diary Full Sample Table 3

Year	Cash		Credit		Debit	
2016	14.1		8.3**		12.4	
95% CI	13.5	14.8	7.8	8.9	11.7	13.1
2017	12.4		8.8		10.9	
95% CI	11.7	13.1	8.1	9.5	10.1	11.7
2018	11.2		10.0		12.2	
95% CI	10.5	11.9	9.3	10.8	11.3	13.0

*Indicates difference is significant at alpha = 0.10
**Indicates difference is significant at alpha = 0.05

2016 and 2018 respectively,[4] with those from the panel reporting 0.6 more cash payments in 2016, and the full sample reporting 0.5 more debit payments per person during the month of October. The 2016 difference in credit card payments is the only statistically significant difference between the two groups with the estimated average number of credit card payments by the panel being one credit card payment per month higher than the full sample.

In terms of both demographic and socioeconomic characteristics, as well as payment instrument use, the group of individuals who selected into the panel do not appear to be different than each year's full Diary sample based on observable characteristics. This suggests that selection bias based on these variables is minimal and results from the panel are likely to be indicative of how payment behavior of the full sample from the 2016 Diary would have evolved if all participants from that year repeated the 2017 and 2018 Diary.

2.3 The Unbanked Population

In addition to the summary statistics described above, *Table 1b* shows the percent of the population for both samples that are either banked or unbanked. Individuals determined to be unbanked do not have either a savings account or a checking account while those who have an account at a financial institution, could be referred to as the banked population.[5] Individuals who are considered to be underbanked are not identified separately for two reasons. First, the population could be considered a subset of the banked population, with the differentiating factor being those who are underbanked have used an alternative financial service within the last 12

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4 Neither cash nor debit card payments in either year are statistically different between the panel and the full Diary sample.

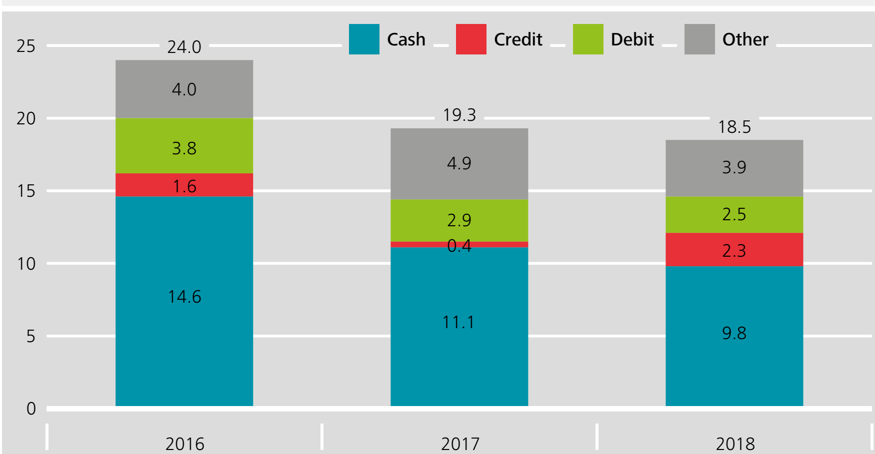
5 The Financial Deposit Insurance Corporation (FDIC) defines the unbanked as individuals who do not have either a checking or a saving account. Underbanked individuals have either a checking or savings account but also used an alternative financial service within the last 12 months. Alternative financial services are defined as payday loans, refund anticipation loans, rent-to-own services, pawn shop loans, and auto title loans.

months. Second, additional analysis (not included) shows the level of consumption, as well as cash and debit card usage, of those who are unbanked to be more in line with those who are considered banked rather than a separate subgroup altogether.

Because those who are unbanked do not have access to traditional financial products, they are far more reliant on cash. As economic conditions improve and the number of individuals who are unbanked declines, the demand for cash as a payment instrument would likely decline as well. At the time of writing this article, the unemployment rate in the United States was 3.8 percent. If individuals who were unbanked and wanted a bank account then benefitted from improved economic conditions, the unbanked population would decrease and the number of individuals with a heavy reliance on cash would decrease. However, the last three years of Diary data show the share of the unbanked population in both the panel and full Diary samples has remained consistent. During this same time period, the number of cash payments and total payments made by unbanked individuals has declined.

Total Payments by Unbanked Participants Figure 1

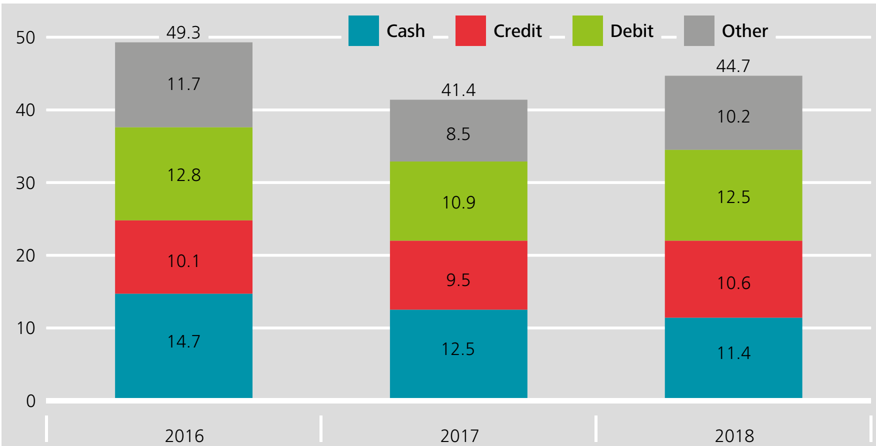
Avg. Number of Payments per Month



Total Payments by Underbanked and Banked Participants

Figure 2

Avg. Number of Payments per Month



Because the unbanked population makes up approximately eight percent of the panel population, less than ten percent of the 1.3 decline in cash payments per person between 2017 and 2018 can be explained by unbanked population.[6]

2.4 Cash and Card acceptance

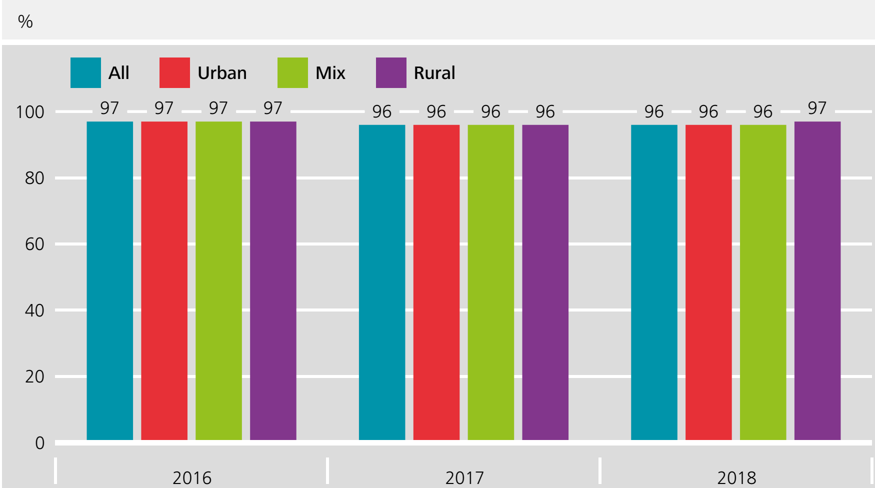
Supply side restrictions of payment instrument use will impact the type of payment instrument used by consumers. The recent news regarding retail establishments not accepting cash has resulted in laws being introduced and, in some cases, passed as cities make operating a retail store that does not accept cash against the law. These laws are intended to make the marketplace fair to all consumers by requiring acceptance of all forms of legal payments. Despite recent news coverage, only one city and

6 This is calculated by using the weighted average of the share of the unbanked and banked population: $Pay_{total} = p \cdot Pay_{unbanked} + (1-p) \cdot Pay_{Non-Unbanked}$

two states currently have such a law in place (Philadelphia, Pennsylvania, and New Jersey and Massachusetts). Other locales may be willing to allow businesses to refuse cash as a payment method. If the trend of cashless stores becomes wide spread, then one should expect to see the rate of cash acceptance decline in the more recent Diary data.[7] However, this is not evident in the data. Even when the data is separated by household location to isolate the fact this trend is likely limited to urban locations, the cash acceptance rate has not statistically changed over the last three years.

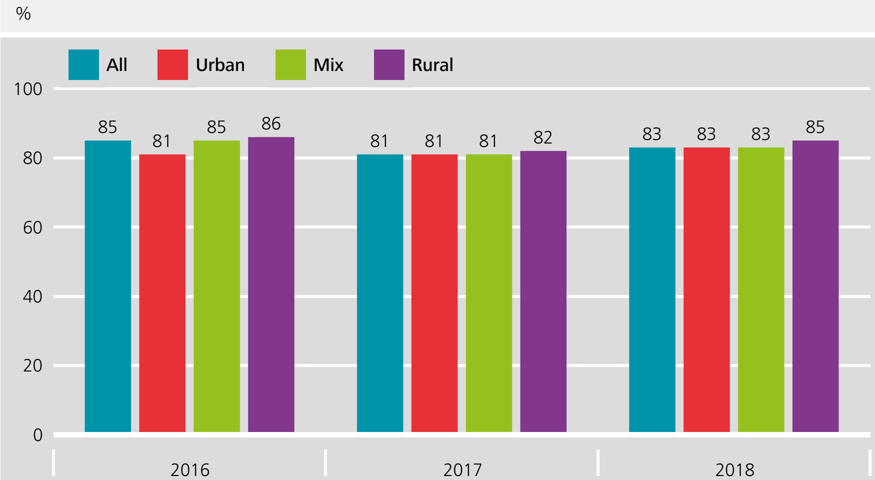
In contrast, if merchants that were once cash only decide to accept card payments, the number of cash payments would likely decrease as those consumers who were previously forced to use cash may now use a payment card.[8] Between 2016 and

Cash Acceptance Rates for In-Person Card Payments Figure 3



7 Individuals are asked a follow-up question about whether cash is accepted for payments that were made using a debit, credit, or prepaid card and if that payment took place in person.
8 *Figure 4* shows the card acceptance rate when excluding individuals who stated "I don't know."

Card Acceptance Rates for In-Person Cash Payments Figure 4

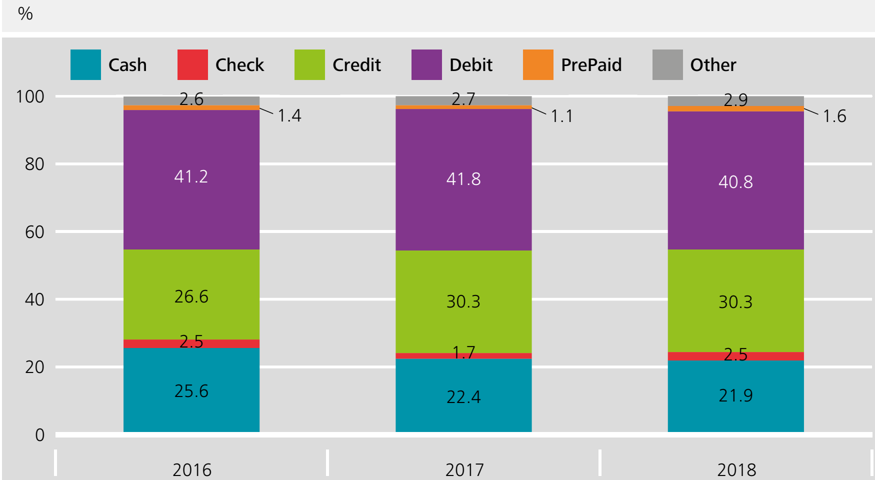


2017, with the exception of individuals who lived in urban locations, the reported change in card acceptance declined rather than increased, with the difference between 2016 and 2017 being statistically significant. However, expanding the analysis and comparing the difference between the data from 2016 and 2018 shows the differences were not statistically significant over this time period. This suggests year to year fluctuations in shopping patterns and participant recollection of specific transactions are likely the cause of these differences rather than a continuously fluctuating rate of card acceptance.

2.5 Payment Preference

One reason why cash usage has declined from 2016 to 2018 is the number of individuals who state cash as their payment preference has decreased. Each year, prior to the start of the Diary, individuals are asked to report the payment instrument they prefer to use for purchases. As *Figure 5* shows, the share of the population

Payment Preferences by Year Figure 5



that prefers cash declined four percentage points in 2017 to 22 percent. Previous literature has shown that those preferring to pay with cash are more likely to use cash and have a higher average number of cash payments per month.[9] As the share of the population that prefers cash declines, a corresponding decline in the number of cash payments is to be expected.

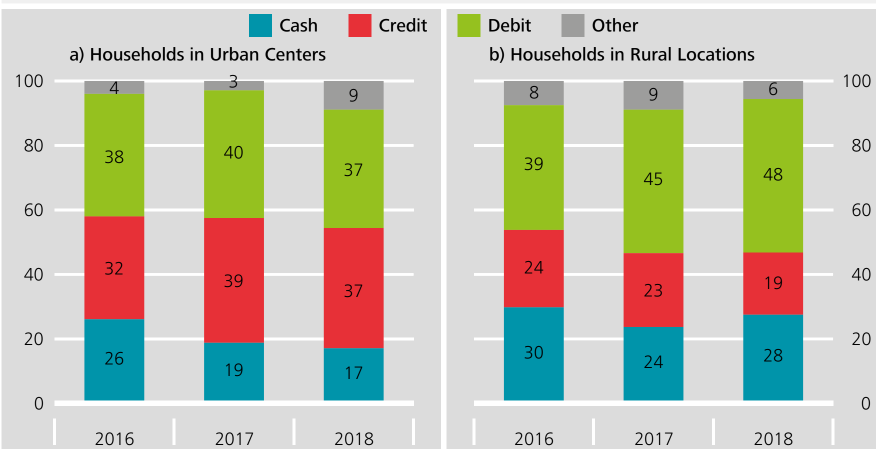
Additionally, *Figures 6* shows how changing preferences differ based on a consumer's residential location.[10] Between 2016 and 2018, the share of individuals preferring cash and living in urban centers declined 9 percentage points, from 26 percent to 17 percent. At the same time, the share of individuals preferring credit increased

9 See O'Brien (2014)
10 The figure showing urban clusters was not included as cash preferences remained consistent between 2016 and 2018

5 percentage points. In contrast, those preferring cash and living in rural locations declined by two percentage points over the same time frame (In 2017 cash preference for those living in rural locations declined six percentage points from the previous year followed by a four percent increase in 2018). The share of the population in rural areas that preferred credit cards also declined 5 percentage points, while the share preferring debit increased nine percentage points during that same period. While these figures do not control for other factors such as household income, education, or race/ethnicity, the differences do highlight how heterogeneous the change in payment preference has been across geographic regions.

Preferences by Households in Urban Centers and Rural Locations Figure 6

%



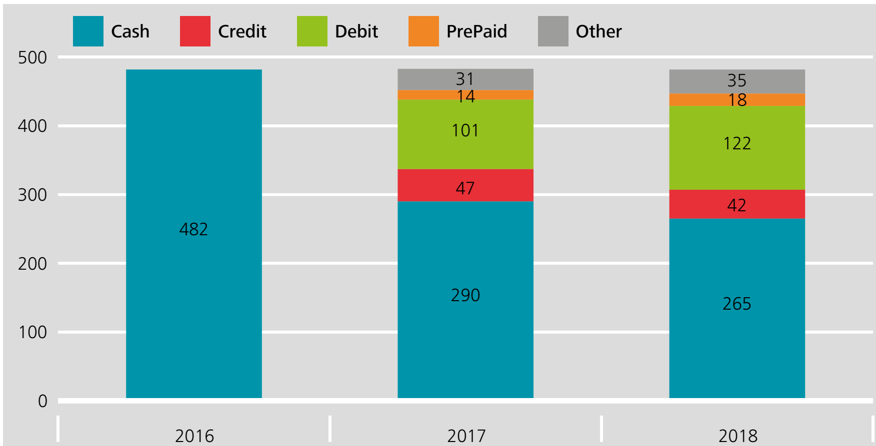
Note: Totals may not sum up to 100% due to rounding.

2.6 Switching Preferences

Each year a share of participants change their preference from what was stated in the previous Diary. The decline in preference for cash is the result of individuals who initially preferred cash switching to another preferences the following year. The charts below show the change in stated preference for 2017 and

Changes in Cash Preference Since 2016

Figure 7

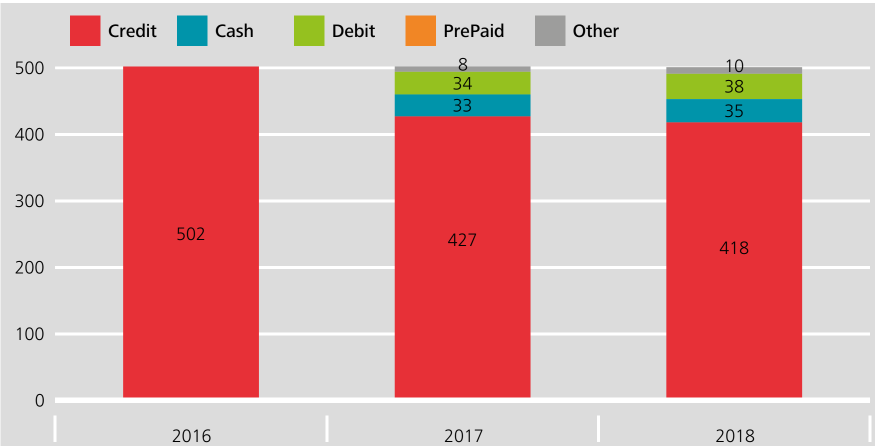


2018 conditional upon an individual's stated preference in 2016 for cash, debit or credit. In 2016, there were 482 individuals who preferred cash, 502 who preferred credit and 777 debit. The corresponding columns report the payment preferences in subsequent years for the same group of individuals. For example, of the 482 individuals who preferred cash in 2016, 290, preferred cash in 2017, 101 preferred debit and 47 preferred credit, 14 pre-paid, and 31 some other instrument.

With respect to the changes that took place for those no longer preferring cash, it is noteworthy that distribution of the changing preferences is quite different than those switching from either a debit or a credit preference in 2016. Those who switched away from debit are distributed nearly equally between then preferring cash and credit and a similar pattern is present place for those switching away from credit. However, most individuals who switched from a cash preference in

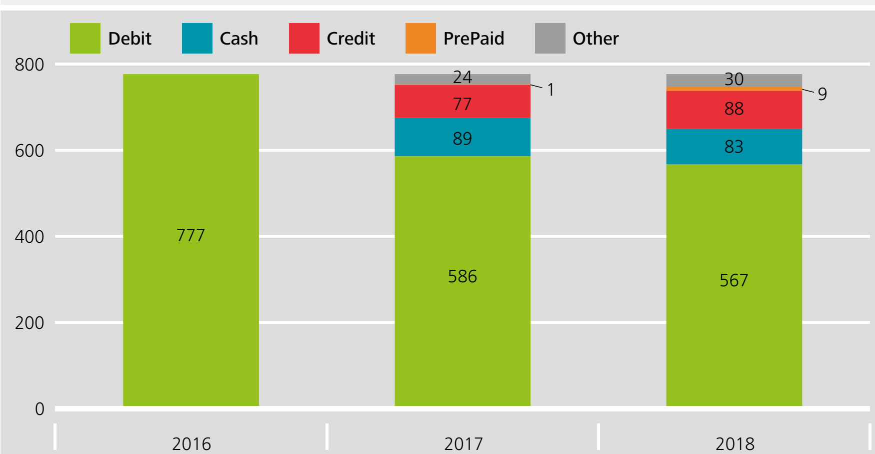
Changes in Credit Preference Since 2016

Figure 8



Changes in Debit Preference Since 2016

Figure 9



2016, preferred debit in 2017.[11] Part of the explanation why approximately two thirds switched to debit versus one third for credit was access to credit. Approximately 36 percent of those who stated a cash preference in 2016 before changing to a debit preference in 2017 did not have a credit card and the same was true for nearly 50 percent of those who preferred cash all three years. While having access to a credit card is necessary for one to prefer using one, it does not explain why a large number of individuals switch away from preferring cash. To better understand why individuals may be switching, additional data from the Survey of Consumer Payment Choice (Survey) is utilized. In the Survey, participants rate different characteristics of each payment instrument each year of participation in the Diary.

2.7 Survey of Consumer Payment Choice

All individuals who participate in the Diary also participate in the Survey. The Survey differs from the Diary in that participants are not asked to report daily transactions, but instead the questions pertain to payment instrument and account adoption, estimated payment instrument use based on recall, as well as assessments of payment instrument characteristics. The ratings provided are the same six characteristics across eight payment instruments.[12] These characteristics are security, acceptance, cost, convenience, initial setup of each payment instrument, and how well records can be kept. The ratings are based on a five point Likert scale[13] and each participant has provided responses for these payment instruments for the last three years.

11 Due to the small number of individuals who stated a preference for a non-cash non-debit, or non-credit payment instrument was small, the preference analysis is limited to cash, debit, and credit.
12 The payment instruments are cash, check, money order, debit card, credit card, prepaid card, bank account number payment, and online banking bill payment.
13 The response options are a variation of very poor, poor, neither good nor poor, good, very good.

Demographic Comparison of All Diary Participants and the Diary Panel Table 4

Cash	Risk	Acceptance	Cost	Conveni-ence	Setting Up	Records
2016	2.8	4.6	4.4	4.0	4.2	2.4
2017	2.8	4.5	4.4	4.0	4.2	2.3***
2018	2.8	4.6	4.4	3.9	4.2	2.2ǂǂǂ
Cash	**Risk**	**Acceptance**	**Cost**	**Conveni-ence**	**Setting Up**	**Records**
2016	3.2	4.6	3.0	4.4	3.7	4.3
2017	3.3**	4.7	3.1	4.4	3.9***	4.4
2018	3.4ǂǂǂ	4.6	3.2ǂǂǂ	4.4	3.8	4.4
Cash	**Risk**	**Acceptance**	**Cost**	**Conveni-ence**	**Setting Up**	**Records**
2016	3.0	4.6	4.1	4.4	4.0	4.3
2017	3.0	4.6	4.2	4.4	4.1	4.3
2018	3.1	4.5	4.2	4.3	4.0	4.3

Stars (*, **, ***) show statistically significant differences from previous year at alpha = 0.1, 0.05, and 0.01, respectively
Crosses (ǂ,ǂǂ,ǂǂǂ) show statistically significant differences between 2016 and 2018 at alpha = 0.1, 0.05, and 0.01, respectively

Table 4 shows that average ratings of the characteristics do not change much from one year to the next. This is not surprising as the fundamental features that make cash, cash and debit cards, debit cards do not change from year-to-year. What may change are participant's perceptions of these characteristics. For example, a person subject to identity theft may drastically change the risk rating of a debit card even though the actual risk in owning and using the card did not change. The data above show that the credit card risk rating increased in 2017 and 2018 and cost ratings for 2018 improved by a statistically significant amount. This improvement in rating may be due to improved economic conditions and consumer's expectations, which then translates into credit being perceived as a lower risk and a less costly payment instrument.

3. Methodology

As described in the introduction, previous work has shown that individuals generally prefer, or home on, one payment instrument. This section provides a framework for how individuals select a preferred payment instrument and then, conditional on the initial preference choice, decide which payment instrument to use for any given payment. A preferred payment instrument is one the individual uses for a plurality, possibly a majority, of payments. What one's preference does not require is that all payments must be made with that payment instrument or that other payment instruments are not preferred in specific circumstances. Instead, one's preference simply changes the likelihood that a specific payment instrument will be used, given the characteristics of each payment.

Let each individual select their payment preference at time t_0^m for a given period $Y_m \in Y$ where $Y = \{Y_1, Y_2, \dots, Y_M\}$ such that Y_m consists of discrete periods of time $Y_m = \{ t_0^m, t_1^m, \dots t_K^m\}$. An individual's payment preference *c*, is chosen from an index of payment instruments, *c* = {1,…,*C*} and is a function of the individual *i*'s demographic characteristics X_{iY_m} and an evaluation of each payment instrument's characteristics Ch_{iY_m} during period Y_m.[14]

(1) $$Prob(Pref_{iY_m} = c) = f(Ch_{iY}, X_{iY})$$

An individual can change one's preference at any time, at which point, the period advances to Y_{m+1} and the notation for the time when the change in preference took place is denoted as t_0^{m+1}. Once an individual has determined their payment preference in period Y_m, the likelihood of payment instrument *s* = {1,…*S*} being used for a given transaction is conditional on one's demographic characteristics, payment preference, and the transaction *j*'s specific characteristics, $Tr_{ijY_m t_k^m}$:

14 The set of payment instruments $\{1, \dots C\}$ a person chooses as a preference is a subset of the number of payment instruments available to use, $\{1, \dots S\}$.

(2) $$Prob\left(N_{ijYt_k^m} = s\right) = f\left(Pref_{iY}, X_{iY}, Tr_{ijYt_k}\right)$$

The transaction specific characteristics, Tr_{ijYt_k} present in the second equation does not incorporate the payment instrument characteristics, Ch_{iY} present in the first equation. It is assumed that the evaluation of each payment instrument and the preference decision took place in the initial period. This seems intuitive as the difficulty of setting up a payment instrument, its record keeping aspect, or the perceived acceptance are already accounted for prior to making the transaction and are unlikely to be taken into account when making everyday purchases.

4. Results

4.1 Payment Preferences

To estimate the preference model described above, a multinomial logit model is used where one's stated payment preference, cash, credit, debit, or other, is regressed on the full set of demographic characteristics and the full set of payment characteristics for cash, debit, and credit for each year of the Diary. Payment characteristics for other payments were not included as those not preferring cash, credit cards, or debit cards, were combined into an "other" preference category.[15]

Tables 5, 6, and *7* show selected marginal effects of the characteristic ratings for each preference model and each year from 2016 to 2018.[16] The reference group for each year's regression was white males, who were not married, working, with college degrees, and living in households making between \$50,000 and \$74,999 per year in a rural location.

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15 The ratings for the payment instruments that are not included are checks, money order, prepaid, bank account number payment, and online banking bill pay.
16 See Appendix for additional regression results.

The results show that for all three years there are several demographic variables that were consistently correlated with one’s payment preference. For instance, women, were less likely to state cash as a preference and more likely to prefer debit and credit cards. Individuals who were married were less likely to prefer debit over cash. With respect to race and ethnicity, black and Hispanic/Latino individuals were less likely to state credit as a preference as compared to cash or debit cards. For both education and household income, individuals who do not hold a college degree, those living in households making less than $25,000, as well as those who were unemployed are more likely to prefer cash to either debit or credit. Participants who hold college degrees, making more than $25,000, or retired were more likely to use credit cards.

While there were a number of statistically significant demographic variables, the ratings on payment characteristics explained for a majority of the variation in the regression. While this makes intuitive sense, there is also no reason to assume that a non-preferred instrument is rated any lower than a preferred instrument. An individual may prefer to use cash, but may rate the record keeping aspect of cash lower than debit or credit. Or someone who prefers using credit cards might look at the application process for obtaining a credit card as fairly tedious to acquire and provide a lower rating than, perhaps, cash.

However, on average, this did not take place. More positive payment characteristic ratings were highly correlated with an individual’s stated preference. How individuals rate these specific characteristics is open to interpretation, especially for characteristics such as cost or convenience. For example, one person who pays their credit card balance in full each month may rate credit card cost as “very low” since rewards provide cash back or other benefits. Another person who carries a balance may characterize credit cards with a “high cost” as interest payments outweigh any benefit rewards may offer. Of all the characteristics, the most correlated characteristic with one’s preference was convenience, followed by cost, then records, and then setup.

Selected Coefficients for Cash Preference from 2016 to 2018

Table 5

	2016	2017	2018
Cash Risk	-0.003 (0.006)	0.001 (0.006)	0.004 (0.006)
Cash Acceptance	-0.011 (0.011)	0.017 (0.012)	0.006 (0.012)
Cash Cost	0.025** (0.011)	0.034*** (0.012)	0.024** (0.011)
Cash Convenience	0.071*** (0.010)	0.045*** (0.010)	0.076*** (0.010)
Cash Setup	0.009 (0.010)	0.024** (0.011)	0.012 (0.011)
Cash Records	0.029*** (0.007)	0.017** (0.007)	0.014* (0.007)
Observations	1855	1857	1859

Selected Marginal Coefficients for Credit Preference from 2016 to 2018

Table 6

	2016	2017	2018
Credit Risk	0.023** (0.010)	0.027*** (0.009)	0.050*** (0.010)
Credit Acceptance	0.011 (0.019)	-0.018 (0.020)	-0.012 (0.021)
Credit Cost	0.066*** (0.007)	0.059*** (0.007)	0.053*** (0.007)
Credit Convenience	0.089*** (0.017)	0.116*** (0.018)	0.108*** (0.018)
Credit Setup	0.030** (0.014)	0.033** (0.013)	0.061*** (0.014)
Credit Records	0.057*** (0.018)	0.087*** (0.018)	0.094*** (0.019)
Observations	1855	1857	1859

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Selected Marginal Coefficients for Debit Preference from 2016 to 2018 Table 7

	2016	2017	2018
Debit Risk	0.019 (0.012)	0.034*** (0.012)	0.054*** (0.012)
Debit Acceptance	0.027 (0.021)	0.053** (0.021)	0.075*** (0.023)
Debit Cost	0.055*** (0.013)	0.050*** (0.013)	0.046*** (0.013)
Debit Convenience	0.145*** (0.018)	0.130*** (0.019)	0.184*** (0.020)
Debit Setup	0.046*** (0.017)	0.063*** (0.017)	0.066*** (0.017)
Debit Records	0.073*** (0.019)	0.079*** (0.018)	0.080*** (0.019)
Observations	1855	1857	1859

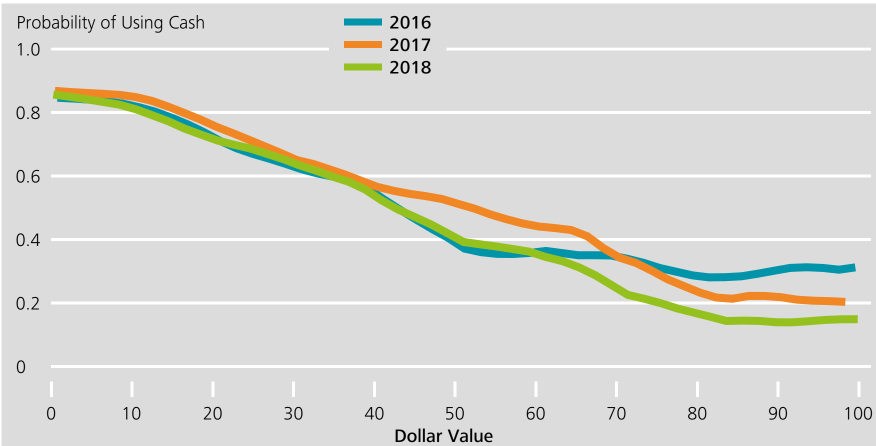
Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

4.2 Cash Use by Payment Preference

To estimate the probability of a cash payment (s=cash) based on equation (2), a random effects logit model was used where a dummy variable indicating a cash payment is regressed on the individual's demographic and transaction characteristics for each stated payment preference separately. Regardless of one's payment preference, the most important variables determining whether cash is used are transaction amount and merchant type.

The regression results for all of the preference groups show little variability between demographic groups. For those that do prefer cash, differences that are present show younger individuals as well as those who are retired are more likely to use cash. Other variables such as employment status and household income are correlated with increased cash use but are only statistically significant in some years.

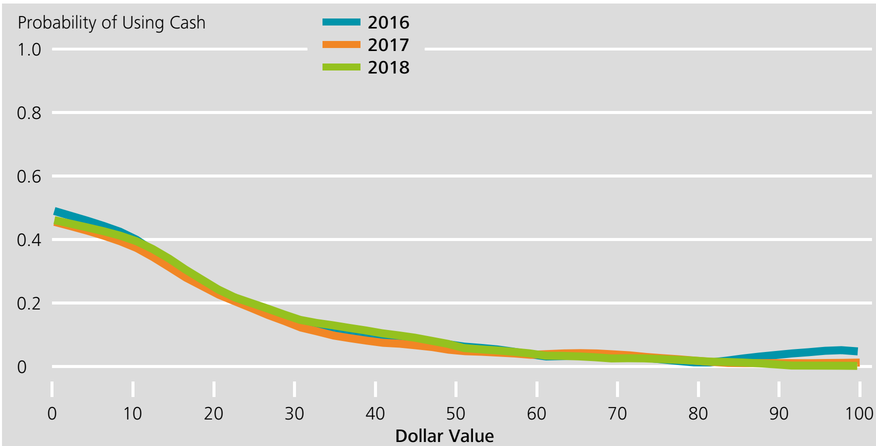
Probability of Cash Use by Those who Prefer Cash Figure 10



For those who prefer debit cards, the results show that individuals who do not hold a college degree, live in households that make less than $50,000 per year or those identifying themselves as black are more likely to use cash than their debit preferring peers. Also, for this preference group, location does not statistically significantly affect cash usage. Those preferring credit cards living in either urban clusters or urban centers are less likely to use cash than those who live in rural locals, while those not holding college degrees and those identifying as Hispanic or Latino are more likely to use cash. Generally, once individuals sort themselves into their preference, their demographic characteristics do not significantly affect the likelihood of using cash. These results contrast from the preference regressions which established that household income, education, race/ethnicity, gender, and employment status are more correlated with preference selection. Essentially, although many factors influence a participant’s stated preference for payment instrument, this preference is not the only factor that impacts the instrument that the participant uses during a transaction.

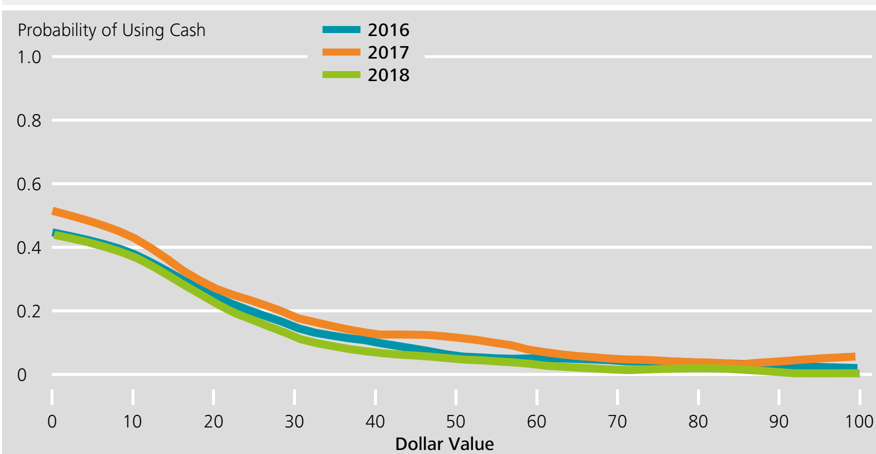
Probability of Cash Use by Those who Prefer Credit

Figure 11



Probability of Cash Use by Those who Prefer Debit

Figure 12



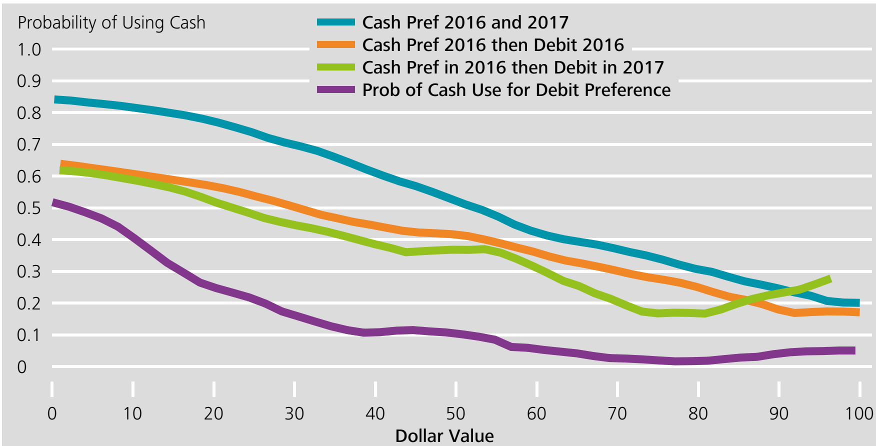
In addition to the regression results described above, the graphs below show the probability of using cash based on one's payment preference. These probabilities are derived from the logit regressions described above. What is interesting about these results is the relative consistency with which each group continues to use cash. Regardless of preference, the likelihood of cash use is statistically unchanged between 2016 and 2018. The only statistically significant difference is 2017, where the probability of cash usage for those preferring cash or debit cards was higher than the previous and subsequent year. The consistent relationship between probability of using cash and the transaction amount for each preference indicates that a key reason for the change in cash use over the last several years has been the shift in payment preference away from cash and towards debit or credit cards. The next section will discuss potential reasons why individuals have been changing their payment preference from one year to the next.

4.3. Changing Payment Preferences

The data show that individuals may be altering their payment behavior prior to changing their stated payment preference. For those who change their preference, there is a shift in the share of payment usage prior to changing their stated preferred payment method where their initial payment preference is used less than those individuals with the same stated payment from one Diary to the next. As an example, individuals who indicated a cash preference in 2016, and then switched to prefer debit cards in 2017 had a lower likelihood of using cash in 2016 compared to the average of those who preferred cash in 2016. Those same individuals also had a lower probability of debit card usage in the first year of stating debit as the preferred payment instrument and tended to use cash more often than others preferring debit cards. The same pattern is present in other groups who changed their preference, whether from cash to debit, or debit to credit, or credit to cash. This suggests that the transition in one's payment habits may not be instantaneous, but rather evolves over time, even if one's preference does change from one period to another.

Changing Preference and the Probability of Cash Use

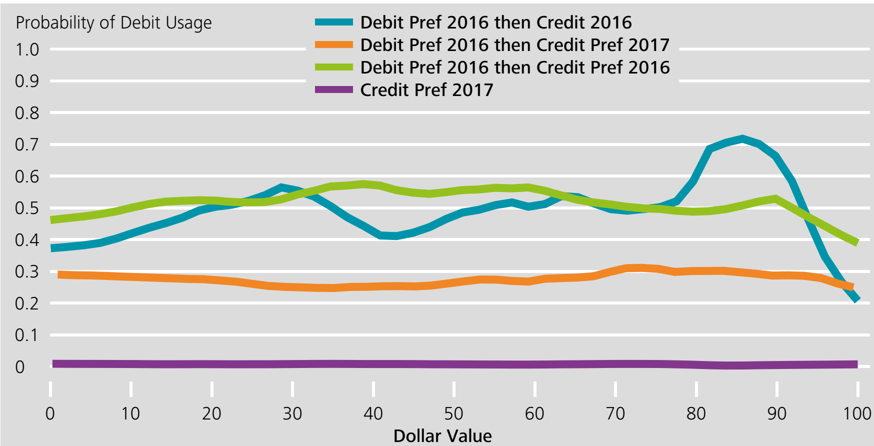
Figure 13



If individuals are shifting their payment instrument usage away from one's currently stated preference and toward their future payment preference, then one indication may be lower payment characteristic ratings prior to the change in payment preference. *Table 8* shows select marginal coefficients from a logit regression of the preference model where characteristic ratings from the previous year are added to the full set of variables described in the payment preference model. The sample for this regression are those who preferred cash in 2016 (2017) and then either preferred cash or debit in 2017 (2018). The results from the 2017 regression indicate that those who switched to a debit preference from a cash preference in 2017 had statistiaclly significant lower convenience rates for cash in 2016 However, this result was not present in the 2018 model. The only consistent results between this preference model and the preference model without last year's characteristic ratings, is how the current year's convenience rating is correlated with preference.

Changing Preferences and the Probability of Debit Use

Figure 14



Selected Marginal Coefficients for Those Preferring Cash one Year and Debit Cards in the Next

Table 8

	2017 Debit Preference	2018 Debit Preference
Cash Cost Last Year	-0.023 (0.026)	-0.012 (0.030)
Cash Convenience Last Year	-0.065*** (0.023)	0.025 (0.025)
Cash Setup Last Year	0.001 (0.027)	-0.062** (0.025)
Cash Records Last Year	-0.018 (0.019)	-0.032* (0.019)
Debit Risk Last Year	-0.003 (0.018)	0.040** (0.019)
Debit Acceptance Last Year	0.020 (0.034)	-0.008 (0.038)
Debit Cost Last Year	-0.017 (0.026)	0.006 (0.028)
Debit Convenience Last Year	0.000 (0.028)	0.055 (0.033)

Debit Setup Last Year	0.072** (0.031)	-0.046 (0.028)
Debit Records Last Year	0.043 (0.031)	0.004 (0.030)
Cash Risk Current Year	0.016 (0.014)	0.028* (0.015)
Cash Acceptance Current Year	-0.013 (0.029)	0.003 (0.025)
Cash Cost Current Year	-0.022 (0.027)	-0.034 (0.029)
Cash Convenience Current Year	-0.015 (0.029)	-0.059*** (0.022)
Cash Setup Current Year	0.013 (0.031)	-0.009 (0.028)
Cash Records Current Year	0.000 (0.019)	-0.002 (0.020)
Debit Risk Current Year	0.013 (0.019)	0.019 (0.019)
Debit Acceptance Current Year	-0.024 (0.033)	0.083** (0.037)
Debit Cost Current Year	0.018 (0.026)	-0.005 (0.028)
Debit Convenience Current Year	0.091*** (0.033)	0.070*** (0.027)
Debit Setup Current Year	0.036 (0.029)	0.040 (0.031)
Debit Records Current Year	-0.009 (0.030)	0.072** (0.030)
N	352	355

As individuals transition from one payment preference to another, payment behavior is different than the average payment usage for that group. Why this takes place and why this transition may take place over time is not known. It could be posited that this particular group of individuals will always have more varied payment choices than most or perhaps this group often changes their payment preferences. Another possability is as time passes, their behavior may trend more towards the mean. Additional observations of panel data is needed to better understand what drives consumer payment choice, but this may indicate that payment preference is a leading indicator of payment instrument usage.

If fewer individuals state cash as their preference in the future, then the share of cash payments will continue to decline. But even if preferences remain consistent for a period of time, as individuals transition away from cash and towards the new payment preference, there is a high likelihood that cash usage will continue to decline until individuals reach a new steady state with a new payment preference.

5. Conclusion

As the results show, uptake in the use of the newly preferred payment instrument is slow in the first year following a change. Thus, as consumers move further away from their switch in preference they will likely to begin to use the newly preferred method more often, which will reduce cash usage even further. Using a subset of individuals who participated in the Diary of Consumer Payment Choice for three consecutive years between 2016 and 2018, the results show how payment preference and usage has changed, and will likely continue to change, moving forward. Participants from this Diary panel show a continuing shift in preference and use of cards over cash. While cash usage has decreased, the probability of using cash for each preference group has remained consistent over the last three years. If the share of individuals who prefer to use cash continues to decline, this decline in preference may be a leading indicator of future cash trends.

The increase in card use also corresponds with a general increase of credit card's risk and convenience ratings provided by participants each year of the Diary. Factors such as changing shopping habits, trust in financial institutions as more time passes from the financial crisis, or how identify theft may change one's assessment of risk may play important roles in one's choice of payment characteristics, and ultimately, preference, but the specific reason remains unclear. Going forward, it will be important to understand how different payment characteristics are important to consumers at different points throughout the business cycle.

6. References

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Appendix

Marginal Coefficients for Selecting Cash as a Payment Preference by Year

Table A1

	2016	2017	2018
Age	-0.001 (0.001)	-0.001 (0.001)	0.001 (0.001)
Married	0.026 (0.020)	0.042** (0.021)	0.028 (0.019)
Female	-0.058*** (0.018)	-0.049*** (0.018)	-0.065*** (0.018)
High School or Less	0.097*** (0.025)	0.122*** (0.025)	0.126*** (0.024)
Some College	0.083*** (0.023)	0.102*** (0.023)	0.092*** (0.022)
Urban Cluster	-0.017 (0.020)	0.000 (0.020)	-0.009 (0.020)
Urban Center	-0.002 (0.027)	-0.007 (0.027)	-0.015 (0.026)
Less than $25k	0.133*** (0.028)	0.090*** (0.030)	0.095*** (0.029)
$25k to $49K	-0.016 (0.028)	0.049* (0.027)	0.040 (0.028)
$75K to 99K	-0.013 (0.034)	0.035 (0.032)	-0.014 (0.033)
$100K to $124K	0.011 (0.038)	0.010 (0.039)	-0.031 (0.039)
More than $125K	-0.002 (0.036)	0.030 (0.035)	0.014 (0.032)
Black	0.024 (0.032)	0.039 (0.030)	0.055* (0.029)
Other Race	0.072** (0.032)	-0.107* (0.059)	-0.058 (0.055)
Hispanic or Latino	0.048 (0.034)	0.045 (0.034)	0.002 (0.036)
Unemployed	0.041 (0.033)	0.141*** (0.034)	0.066* (0.037)
Disabled	0.012 (0.029)	0.062** (0.027)	-0.008 (0.027)
Retired	-0.001 (0.028)	-0.021 (0.028)	-0.056** (0.027)
Cash Risk	-0.003 (0.006)	0.001 (0.006)	0.004 (0.006)
Cash Acceptance	-0.011 (0.011)	0.017 (0.012)	0.006 (0.012)
Cash Cost	0.025** (0.011)	0.034*** (0.012)	0.024** (0.011)

Cash Convenience	0.071*** (0.010)	0.045*** (0.010)	0.076*** (0.010)
Cash Setup	0.009 (0.010)	0.024** (0.011)	0.012 (0.011)
Cash Records	0.029*** (0.007)	0.017** (0.007)	0.014* (0.007)
Credit Risk	-0.017* (0.010)	0.002 (0.010)	0.000 (0.010)
Credit Acceptance	-0.037** (0.015)	0.035** (0.017)	-0.004 (0.017)
Credit Cost	-0.017** (0.007)	-0.013* (0.007)	-0.005 (0.007)
Credit Convenience	-0.011 (0.013)	-0.043*** (0.012)	-0.017 (0.014)
Credit Setup	-0.021** (0.010)	-0.012 (0.011)	-0.019* (0.011)
Credit Records	0.004 (0.014)	-0.008 (0.014)	-0.011 (0.015)
Debit Risk	-0.001 (0.010)	-0.000 (0.010)	-0.001 (0.010)
Debit Acceptance	0.007 (0.016)	-0.022 (0.016)	-0.023 (0.016)
Debit Cost	-0.028*** (0.011)	-0.011 (0.011)	-0.011 (0.011)
Debit Convenience	-0.035** (0.013)	-0.041*** (0.013)	-0.076*** (0.014)
Debit Setup	0.014 (0.013)	-0.018 (0.013)	-0.007 (0.014)
Debit Records	-0.034** (0.014)	-0.039*** (0.013)	-0.035** (0.014)
Observations	1855	1857	1859
Pseudo R2			

Marginal Coefficients for Selecting Credit as a Payment Preference by Year

Table A2

	2016	2017	2018
Age	0.001 (0.001)	0.001 (0.001)	0.001 (0.001)
Married	-0.006 (0.020)	0.002 (0.022)	-0.002 (0.020)
Female	-0.007 (0.018)	-0.000 (0.018)	0.003 (0.018)
High School or Less	-0.125*** (0.026)	-0.144*** (0.026)	-0.150*** (0.026)
Some College	-0.095*** (0.020)	-0.114*** (0.020)	-0.105*** (0.019)

Urban Cluster	0.002 (0.021)	0.028 (0.021)	-0.005 (0.021)
Urban Center	0.023 (0.026)	0.080*** (0.026)	0.034 (0.025)
Less than $25k	-0.045 (0.033)	-0.075** (0.036)	-0.070** (0.032)
$25k to $49K	-0.015 (0.027)	-0.039 (0.026)	-0.036 (0.028)
$75K to 99K	-0.013 (0.028)	-0.032 (0.028)	-0.016 (0.028)
$100K to $124K	0.029 (0.031)	0.021 (0.032)	0.011 (0.031)
More than $125K	0.054* (0.028)	0.020 (0.028)	0.041 (0.027)
Black	-0.061 (0.041)	-0.056 (0.037)	-0.102*** (0.039)
Other Race	0.046 (0.033)	0.161*** (0.046)	0.129*** (0.045)
Hispanic or Latino	-0.085** (0.042)	-0.071* (0.042)	-0.121*** (0.046)
Unemployed	-0.096** (0.047)	-0.125** (0.055)	-0.038 (0.054)
Disabled	-0.083** (0.041)	-0.013 (0.037)	-0.036 (0.037)
Retired	0.055** (0.027)	0.087*** (0.026)	0.055** (0.026)
Cash Risk	-0.006 (0.006)	-0.007 (0.006)	-0.009 (0.006)
Cash Acceptance	-0.005 (0.011)	0.007 (0.011)	0.008 (0.011)
Cash Cost	-0.013 (0.011)	-0.007 (0.011)	0.010 (0.011)
Cash Convenience	-0.020** (0.008)	-0.004 (0.009)	-0.025*** (0.008)
Cash Setup	0.014 (0.010)	-0.015 (0.010)	-0.003 (0.010)
Cash Records	-0.011 (0.007)	-0.019** (0.008)	-0.014* (0.008)
Credit Risk	0.023** (0.010)	0.027*** (0.009)	0.050*** (0.010)
Credit Acceptance	0.011 (0.019)	-0.018 (0.020)	-0.012 (0.021)
Credit Cost	0.066*** (0.007)	0.059*** (0.007)	0.053*** (0.007)
Credit Convenience	0.089*** (0.017)	0.116*** (0.018)	0.108*** (0.018)
Credit Setup	0.030** (0.014)	0.033** (0.013)	0.061*** (0.014)
Credit Records	0.057*** (0.018)	0.087*** (0.018)	0.094*** (0.019)

Debit Risk	-0.019** (0.010)	-0.040*** (0.009)	-0.048*** (0.010)
Debit Acceptance	-0.022 (0.017)	-0.033** (0.017)	-0.040** (0.018)
Debit Cost	-0.027** (0.011)	-0.034*** (0.011)	-0.033*** (0.012)
Debit Convenience	-0.097*** (0.014)	-0.079*** (0.015)	-0.100*** (0.016)
Debit Setup	-0.055*** (0.015)	-0.043*** (0.015)	-0.060*** (0.016)
Debit Records	-0.032** (0.014)	-0.023 (0.015)	-0.025 (0.015)
Observations	1855	1857	1859
Pseudo R2			

Marginal Coefficients for Selecting Debit as a Payment Preference by Year

Table A3

	2016	2017	2018
Age	0.000 (0.001)	0.000 (0.001)	-0.001 (0.001)
Married	-0.039* (0.023)	-0.022 (0.025)	-0.044* (0.022)
Female	0.039* (0.021)	0.045** (0.021)	0.065*** (0.021)
High School or Less	0.000 (0.030)	0.007 (0.030)	-0.008 (0.029)
Some College	-0.023 (0.025)	-0.007 (0.025)	-0.015 (0.024)
Urban Cluster	0.016 (0.024)	-0.018 (0.024)	0.013 (0.024)
Urban Center	-0.004 (0.031)	-0.001 (0.031)	-0.004 (0.030)
Less than $25k	-0.106*** (0.036)	-0.041 (0.039)	-0.051 (0.035)
$25k to $49K	-0.001 (0.032)	-0.024 (0.031)	-0.021 (0.032)
$75K to 99K	0.028 (0.035)	-0.007 (0.035)	0.047 (0.035)
$100K to $124K	-0.040 (0.042)	-0.038 (0.042)	-0.003 (0.040)
More than $125K	-0.043 (0.039)	-0.042 (0.039)	-0.044 (0.036)
Black	0.005 (0.041)	-0.011 (0.038)	0.010 (0.037)
Other Race	-0.114*** (0.041)	-0.029 (0.064)	-0.094 (0.062)

Hispanic or Latino	0.008 (0.043)	-0.008 (0.043)	0.060 (0.044)
Unemployed	0.049 (0.045)	-0.019 (0.053)	-0.063 (0.051)
Disabled	0.077** (0.039)	-0.066* (0.038)	0.035 (0.036)
Retired	-0.055 (0.034)	-0.052 (0.033)	0.004 (0.032)
Cash Risk	0.005 (0.007)	0.005 (0.007)	0.005 (0.007)
Cash Acceptance	0.016 (0.013)	-0.023* (0.012)	-0.021 (0.013)
Cash Cost	-0.014 (0.013)	-0.029** (0.013)	-0.031** (0.013)
Cash Convenience	-0.051*** (0.010)	-0.040*** (0.010)	-0.050*** (0.010)
Cash Setup	-0.015 (0.011)	-0.016 (0.012)	-0.007 (0.012)
Cash Records	-0.021** (0.009)	-0.001 (0.009)	-0.003 (0.009)
Credit Risk	-0.013 (0.011)	-0.026** (0.012)	-0.052*** (0.012)
Credit Acceptance	0.032 (0.020)	0.004 (0.023)	0.019 (0.023)
Credit Cost	-0.051*** (0.008)	-0.044*** (0.008)	-0.044*** (0.008)
Credit Convenience	-0.088*** (0.017)	-0.077*** (0.018)	-0.102*** (0.020)
Credit Setup	0.006 (0.014)	-0.021 (0.014)	-0.043*** (0.014)
Credit Records	-0.071*** (0.019)	-0.084*** (0.019)	-0.085*** (0.021)
Debit Risk	0.019 (0.012)	0.034*** (0.012)	0.054*** (0.012)
Debit Acceptance	0.027 (0.021)	0.053** (0.021)	0.075*** (0.023)
Debit Cost	0.055*** (0.013)	0.050*** (0.013)	0.046*** (0.013)
Debit Convenience	0.145*** (0.018)	0.130*** (0.019)	0.184*** (0.020)
Debit Setup	0.046*** (0.017)	0.063*** (0.017)	0.066*** (0.017)
Debit Records	0.073*** (0.019)	0.079*** (0.018)	0.080*** (0.019)
Observations	1855	1857	1859
Pseudo R2			

Marginal Coefficients of Cash Use by those Preferring Cash

Table A4

	2016	2017	2018
Amount	-0.043*** (0.01)	-0.044*** (0.01)	-0.058*** (0.01)
Amount Sq.	0.000*** (0.00)	0.000*** (0.00)	0.000*** (0.00)
Age	0.158** (0.07)	0.117 (0.08)	0.124 (0.09)
Age Sq.	-0.002** (0.00)	-0.001 (0.00)	-0.001* (0.00)
Married	0.142 (0.33)	-0.285 (0.37)	0.035 (0.37)
Female	0.433 (0.30)	-0.074 (0.31)	-0.396 (0.33)
High School or Less	0.841** (0.43)	0.270 (0.45)	0.367 (0.43)
Some College	0.291 (0.38)	0.358 (0.41)	0.576 (0.40)
Urban Cluster	-0.449 (0.33)	-0.342 (0.36)	-0.335 (0.36)
Urban Center	-0.848** (0.42)	-0.445 (0.46)	-0.189 (0.48)
Less than $25k	0.575 (0.47)	0.893 (0.57)	0.927 (0.57)
$25k to $49K	0.583 (0.50)	0.488 (0.48)	1.059** (0.52)
$75K to 99K	0.380 (0.61)	-0.504 (0.56)	0.592 (0.60)
$100K to $124K	0.721 (0.61)	-0.165 (0.71)	-0.814 (0.69)
More than $125K	0.332 (0.57)	-0.146 (0.61)	-0.385 (0.56)
Black	0.284 (0.56)	-0.045 (0.55)	-0.114 (0.57)
Other Race	-0.507 (0.46)	-1.385 (1.04)	-0.966 (0.96)
Hispanic or Latino	-0.296 (0.54)	1.042 (0.67)	0.142 (0.68)
Unemployed	1.484** (0.67)	0.551 (0.63)	0.028 (0.84)
Disabled	0.633 (0.47)	0.210 (0.50)	0.825 (0.57)
Retired	1.132** (0.53)	0.887* (0.53)	1.005* (0.53)
N	1520	1274	1290

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Marginal Coefficients of Cash Use by those Preferring Credit

Table A5

	2016	2017	2018
Amount	-0.085*** (0.01)	-0.103*** (0.01)	-0.092*** (0.01)
Amount Sq.	0.000*** (0.00)	0.000*** (0.00)	0.000*** (0.00)
Age	0.050 (0.05)	0.168*** (0.05)	0.125** (0.05)
Age Sq.	-0.000 (0.00)	-0.001** (0.00)	-0.001* (0.00)
Married	-0.223 (0.25)	-0.525* (0.29)	-0.004 (0.27)
Female	-0.115 (0.20)	0.083 (0.23)	0.076 (0.23)
High School or Less	0.408 (0.35)	0.704* (0.37)	0.803** (0.40)
Some College	0.331 (0.25)	0.000 (0.26)	0.541* (0.28)
Some College	-0.533** (0.25)	-0.827*** (0.28)	-0.664** (0.28)
Urban Cluster	-0.298 (0.28)	-0.841** (0.33)	-1.023*** (0.32)
Less than $25k	-0.299 (0.45)	-0.268 (0.51)	0.031 (0.47)
$25k to $49K	0.855** (0.34)	0.484 (0.36)	0.232 (0.41)
$75K to 99K	0.596* (0.31)	-0.128 (0.35)	0.017 (0.35)
$100K to $124K	0.741** (0.32)	0.365 (0.36)	0.591 (0.40)
More than $125K	0.556* (0.29)	-0.019 (0.31)	0.492 (0.33)
Black	-0.127 (0.62)	0.058 (0.59)	0.231 (0.63)
Other Race	0.108 (0.34)	0.941** (0.45)	-0.270 (0.51)
Hispanic or Latino	0.378 (0.58)	0.436 (0.61)	1.104 (0.70)
Unemployed	0.557 (0.57)	-0.391 (0.78)	-0.631 (0.97)
Disabled	-0.127 (0.58)	0.752 (0.57)	0.747 (0.58)
Retired	-0.090 (0.29)	0.117 (0.34)	0.130 (0.33)
N	2486	2592	2657

Standard errors in parentheses
* p < 0.10, ** p < 0.05, *** p < 0.01

Marginal Coefficients of Cash Use by those Preferring Debit

Table A6

	2016	2017	2018
Amount	-0.072*** (0.01)	-0.075*** (0.01)	-0.095*** (0.01)
Amount Sq.	0.000*** (0.00)	0.000*** (0.00)	0.000*** (0.00)
Age	0.118*** (0.04)	0.062 (0.05)	0.028 (0.05)
Age Sq.	-0.001** (0.00)	-0.000 (0.00)	0.000 (0.00)
In-Person	-0.041 (0.20)	0.540** (0.24)	-0.460** (0.23)
Married	-0.116 (0.19)	0.358* (0.21)	0.128 (0.21)
Female	0.795*** (0.25)	1.208*** (0.29)	0.916*** (0.29)
High School or Less	0.486** (0.20)	0.735*** (0.23)	0.253 (0.23)
Some College	-0.081 (0.21)	0.227 (0.23)	-0.348 (0.23)
Urban Cluster	0.203 (0.27)	0.195 (0.29)	-0.329 (0.30)
Less than $25k	0.147 (0.31)	1.517*** (0.37)	0.171 (0.34)
$25k to $49K	0.033 (0.26)	0.349 (0.29)	0.587* (0.31)
$75K to 99K	-0.408 (0.28)	-0.355 (0.32)	0.583* (0.33)
$100K to $124K	-0.458 (0.34)	0.292 (0.38)	-0.204 (0.37)
More than $125K	-0.216 (0.34)	0.168 (0.36)	0.424 (0.36)
Black	0.653* (0.36)	1.206*** (0.38)	0.968** (0.38)
Other Race	-0.324 (0.39)	0.276 (0.71)	1.013 (0.69)
Hispanic or Latino	-0.161 (0.42)	-0.023 (0.42)	-0.027 (0.42)
Unemployed	-0.433 (0.42)	-0.726 (0.56)	-0.022 (0.53)
Disabled	0.476 (0.31)	-0.473 (0.39)	-0.270 (0.36)
Retired	0.357 (0.32)	-0.247 (0.36)	0.411 (0.34)
N	3766	3272	3217

Logit Marginal Coefficients for Those Preferring Cash one Year and Debit Cards in the Next

Table A7

	2017 Debit Preference	2018 Debit Preference
Age	-0.004** (0.002)	-0.004** (0.002)
Married	-0.088* (0.049)	-0.086* (0.048)
Female	0.018 (0.045)	0.104** (0.044)
High School or Less	0.021 (0.072)	-0.002 (0.074)
Some College	0.015 (0.067)	0.006 (0.068)
Urban Cluster	0.026 (0.050)	0.118** (0.047)
Urban Center	0.020 (0.065)	0.147** (0.066)
Less than $25,000	-0.035 (0.070)	-0.065 (0.069)
$25,000 – $49,999	-0.045 (0.066)	-0.040 (0.069)
$75,000 – $99,999	-0.126 (0.087)	0.100 (0.083)
$100,000 – $124,999	-0.164 (0.123)	0.185* (0.100)
Greater than $125,000	-0.198* (0.116)	0.057 (0.089)
Black	-0.042 (0.074)	-0.074 (0.075)
Other Race	0.190* (0.112)	0.037 (0.176)
Hispanic or Latino	0.026 (0.077)	-0.058 (0.080)
Unemployed	-0.162* (0.083)	-0.074 (0.094)
Disabled	-0.022 (0.063)	0.103* (0.061)
Retired	0.031 (0.076)	0.048 (0.070)
Cash Risk Last Year	-0.002 (0.015)	0.007 (0.014)
Cash Acceptance Last Year	-0.028 (0.028)	0.078** (0.035)
Cash Cost Last Year	-0.023 (0.026)	-0.012 (0.030)

Cash Convenience Last Year	-0.065*** (0.023)	0.025 (0.025)
Cash Setup Last Year	0.001 (0.027)	-0.062** (0.025)
Cash Records Last Year	-0.018 (0.019)	-0.032* (0.019)
Debit Risk Last Year	-0.003 (0.018)	0.040** (0.019)
Debit Acceptance Last Year	0.020 (0.034)	-0.008 (0.038)
Debit Cost Last Year	-0.017 (0.026)	0.006 (0.028)
Debit Convenience Last Year	0.000 (0.028)	0.055 (0.033)
Debit Setup Last Year	0.072** (0.031)	-0.046 (0.028)
Debit Records Last Year	0.043 (0.031)	0.004 (0.030)
Cash Risk Current Year	0.016 (0.014)	0.028* (0.015)
Cash Acceptance Current Year	-0.013 (0.029)	0.003 (0.025)
Cash Cost Current Year	-0.022 (0.027)	-0.034 (0.029)
Cash Convenience Current Year	-0.015 (0.029)	-0.059*** (0.022)
Cash Setup Current Year	0.013 (0.031)	-0.009 (0.028)
Cash Records Current Year	0.000 (0.019)	-0.002 (0.020)
Debit Risk Current Year	0.013 (0.019)	0.019 (0.019)
Debit Acceptance Current Year	-0.024 (0.033)	0.083** (0.037)
Debit Cost Current Year	0.018 (0.026)	-0.005 (0.028)
Debit Convenience Current Year	0.091*** (0.033)	0.070*** (0.027)
Debit Setup Current Year	0.036 (0.029)	0.040 (0.031)
Debit Records Current Year	-0.009 (0.030)	0.072** (0.030)
N	352	355

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Cash Use and Financial Literacy[1]

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Abstract

The Bank of Canada, as the sole issuer of banknotes, monitors trends in the adoption and use of cash relative to other methods of payment. The recent 2017 Methods- of-Payment (MOP) Survey Report found that cash use at the point-of-sale declined between 2009 and 2017, but that cash was still used for about one-third of transactions, see Henry et al. (2018). Understanding the determinants of cash usage is important for understanding the evolution. One possibility is financial literacy, or the knowledge is required to navigate the growing array of payment methods. The 2017 MOP found that respondents with lower financial literacy, as

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measured by the "Big Three" test questions (Lusardi and Mitchell (2011a)), was associated with higher cash holdings and usage, higher debit card usage, and lower credit card usage. We find a variety of credit card restrictions on individuals with low financial literacy and consider its role as a possible constraining factor in the interplay between financial literacy and cash usage.

1 Introduction

The Bank of Canada, as the sole issuer of banknotes, monitors trends in the adoption and use of cash and other methods of payment. Based on the 2017 Methods-of-Payment (MOP) Survey Report, see Henry et al. (2018), found that cash use for retail payments declined between 2009 and 2017–in terms of number of transactions, from 54 to 33 percent, and in terms of value of transactions, from 23 to 15 percent. The survey report dedicated a section to financial literacy, finding in particular that lower literacy was associated with a higher amount of cash held in the respondents' purse or wallet (in particular the holding of large-denomination notes), a greater number of trips to the ABM to withdraw cash, and a greater likelihood of using cash at the point-of-sale.

To understand a potential determinants of cash usage, we focus on financial literacy, observing that literacy is a significant predictor of various aspects of payment behaviour even after controlling for other factors in a regression setting. We also identify some of the demand- and supply-side factors that may ultimately be driving these behaviours. We measure financial literacy using the "Big Three" literacy questions, which were developed in the context of studying the effects of literacy on retirement planning (Lusardi and Mitchell (2011a)) and have appeared on many national surveys around the globe (Lusardi and Mitchell (2011b)).

Lower literacy has been found to be associated with many other financial outcomes. Hastings et al. (2013) provides an in-depth review of the literature on financial literacy while Van Rooij et al. (2011) discusses lower stock market participation. The correlation between financial literacy and payment behaviour has been studied before mostly in the context of credit card use. Lusardi and Tufano (2015) find a link between debt illiteracy and incurring unnecessary costs associated with credit card fees and measure a so-called "cost of ignorance." Allgood and Walstad (2013) additionally find higher literacy to be associated with positive behaviours such as paying balances in full and avoiding unnecessary interest charges and fees. Low financial literacy has also been linked to the adoption of payment innovations; Lusardi et al. (2018) find that, among millennials, mobile payment users are more likely than non-users to overdraw their checking account. Further, Henry et al. (2019) find that those with low literacy are less likely to have heard of Bitcoin, yet are more likely to own it overall.

Using the "Big Three" questions, we classify respondents into low, medium, and high financial literacy. We find that low-literacy respondents are more likely to have used payment innovations in the past year to make purchases and person-to-person transfers. This includes mobile payments, online payment accounts like PayPal, and digital currencies like Bitcoin. Additionally, lower literacy respondents make a greater share of their payments using cash and debit at the expense of credit cards. To help explain behavioural differences, we examine some demand- and supply-side factors. We find that low-literacy respondents perceive payment innovations to be more widely accepted by merchants than their high-literacy counterparts. Further, they view debit and credit cards as easier, less costly, and more secure to use. Debit and credit are viewed similarly by low-literacy respondents except that credit cards are viewed to be more costly. This group uses cash and debit more often than credit, perhaps due to these perceived costs or to supply-side constraints–they are less likely to own a credit card, have poorer credit, and are more likely to revolve on their debt.

The remainder of the paper is organized into the following sections. In Section 2 we describe the various data sources we use in our analysis. In Section 3 we introduce our proxy of financial literacy and describe some overall trends in Canada. In Section 4 we describe trends in payment adoption and use and how these relate to financial literacy. Section 5 looks at the relationship between financial literacy and cash holdings, and the possible role of credit card adoption within it. Section 6 concludes.

2 Survey and administrative data

Our work relies mostly on the 2017 MOP survey conducted in late 2017. The survey consisted of two components; the Survey Questionnaire (SQ), and the Diary Survey Instrument (DSI). The SQ asked respondents retrospectively about certain payment behaviours–for example, if a respondent had used a method of payment in the last year, the number and value of cash withdrawals made in a typical month, and the number of times each method of payment was used in a typical month. The DSI asked respondents to report, over a three-day period, the purchases they made, the amount spent on the purchase, and the method of payment used to complete the transaction. They were also asked to report any withdrawals or deposits of cash made over the period. For further details on the number of responses and summary statistics on many of the questions, see Henry et al. (2018). As the survey is a non-probability sample, survey weights are used to reduce bias in estimates. Weights are calibrated with respect to various demographic variables and bootstrap replication is used for variance estimation; for a full discussion of methodology, see Chen et al. (2018).

The SQ asked respondents to report their exact credit scores if they knew them, or to choose their best guess from pre-selected checkboxes, see *Figure 6*. However, few (15.5 percent) reported their exact score, and those credit scores that are collected may be subject to measurement error if, for example, respondents do not look up their exact score but instead produce it from memory. To improve data on credit scores, we cross-validate the 2017 MOP with anonymized data from TransUnion. Ho et al. (2019) use this methodology to understand home equity extraction in Canada. Using characteristics from the 2017 MOP, we conduct matching based on: the forward sorting area (FSA), number of credit cards, and various other banking indicators. The process is similar to that of Hayashi and Stavins (2012), who use Equifax data to match credit scores to their payments survey. Not every respondent has a unique match, so we impute remaining observations using a k-nearest neighbour's algorithm on various demographic variables. For a full discussion of the matching process and imputation, see Appendix A.1.

Another external source of supply-side information, collected by Mintel, comes from the number of credit card solicitations sent by letter or email. These offers can contain invitations to apply for new cards, collect rewards points, or increase credit limits. Mail advertisements are matched based on FSA, while this is not available for email-based ads. Thus, the email and combined datasets are only matched to MOP participants at the rougher provincial level. See Appendix A.2 for more details. *Table 1* provides a summary of the data sources used in this paper and their corresponding sample sizes.

Summary of data sources Table 1

	SQ	DSI
Sample size	3123	2187
Credit score sample		
Self-reported	483	316
TU match	2747	1939
TU imputed	3123	2187
Mintel sample		
Email	2436	1661
Direct mail	734	570
Combined	3120	2184

Note: Self-reported credit scores are based on voluntary survey responses in the MOP SQ. TU Match refers to matching observations to TransUnion credit scores based on their own FSA and demographics. TU Imputed refers to imputing for unmatched respondents. Refer to Appendix A.1 for more details.

3 Measuring financial literacy

Our measure of financial literacy is based on the "Big Three" questions, as defined by Lusardi and Mitchell (2011a), relating to an individual's understanding of financial instruments (*Table 2*). The questions test the respondents' knowledge of simple compound interest, inflation, and risk diversification, respectively. The questions are multiple choice, with the option for respondents to answer, "Don't Know." Overall, we found that 83 per cent of respondents answered the question about interest rates correctly, 64 per cent answered the inflation question correctly, and only 58 answered per cent answered the question on risk diversification correctly. Furthermore, 42 per cent of respondents answered all three questions correctly. When examining "Don't Know" rates, we find a similar trend, with the smallest proportion of respondents answering "Don't Know" to the first question (6.6 percent) and the highest to the third question (34 percent), while 12.5 per cent responded "Don't Know" to the second question. In an international context, we find that Canadians seem to be in the middle of the pack, performing better than countries such as the United States (30 per cent) and Russia (4 per cent), but worse than Germany (53 per cent) and Switzerland (50 per cent) (Lusardi and Mitchell (2014)). Our results are most similar to those of Australia (43 per cent).

Other surveys have been conducted in Canada that test various aspects of financial literacy. A recent Equifax survey[2] found that 52 per cent of Canadians check their credit scores at least once in their lives, in contrast to 27 per cent of Americans. Our results are consistent with Boisclair et al. (2017) who the same questions and similarly found that 42 per cent of Canadians answered all three literacy questions correctly.

For this paper, we construct a single measure of financial literacy, dividing the population into low, medium, and high literacy categories. To do this we measure

2 https://www.nasdaq.com/press-release/making-the-grade-in-financial-literacy-canadians-still-have-a-lot-to-learn-20181127-00177

a score equal to the number of correct responses minus the number of incorrect responses, treating "Don't Know" responses as 0.[3] High financial literacy is then defined as a score of 3 (all three questions answered correctly), medium financial literacy as a score of 2 or 1 (more correct than incorrect responses, but not perfect), and low financial literacy as a score of 0 or less (answered "Don't Know" to all questions or answered more incorrect than correct).

Regressing our measure of literacy on various sociodemographic characteristics,[4] we find that financial literacy tends to increase with age, education, and income. Across genders, females tend to be less financially literate than males. Household size does not appear to be significant except in the case of households with 3 or more members, which tend to have lower financial literacy than households with one member. Other demographic variables included in the Methods-of-Payment survey such as employment status, marital status, and urban/rural do not appear to be significant overall.

As a first look into how cash demand is related to financial literacy, we use the international comparison of literacy collected by Lusardi and Mitchell (2014) and compare to the country's cash intensity as measured by the value of banknotes in circulation as a fraction of nominal GDP (*Figure 1*). Financial literacy is measured here by the percentage of individuals in each country who got all questions correct–i.e. our measure of "high" literacy. We note the presence of outliers: first is Japan, known to be highly cash-intensive, and second are Romania and Russia, with very low levels of financial literacy. For remaining countries there does appear to be a positive trend between literacy and cash usage as measured by the total value of cash in circulation as a share of GDP. Bagnall et al. (2016) provide a comparison of cash holdings based on surveys from various surveys and similarly show Germany

3 This corresponds to score2 in Henry et al. (2018).
4 Results available upon request

to be the most cash-intensive and literate. As we will see, our findings of a positive relationship between literacy and cash does not carry over to the micro level within Canada, suggesting perhaps that there are unobserved country-specific factors that are correlated with both cash use and literacy.

4 Financial literacy and payments

4.1 Adoption of payment cards and emerging technologies

As shown in the 2017 MOP report (Henry et al. (2018)), ownership of debit cards is nearly universal in Canada, and this is true regardless of one's level of financial literacy.[5] On the other hand, credit cards are owned by about 89 percent of Canadians, and this varies by level of financial literacy, even after controlling for other sociodemographic factors such as income. Compared to low-literacy respondents, medium literacy is associated with 8 percent higher adoption of credit cards while high literacy is associated with 16 percent higher adoption (*Table 5*).

Even those who have credit cards are nonetheless constrained in several ways. Low-literacy card-holders have lower limits on their main credit card and are more likely to have annual fees. Further, financial literacy is correlated with credit scores, whether they are self-reported or based on matches to TransUnion data (*Table 6*). The exact method for computing scores is not known, but they are based on the following items: payment history, amount owed, types of credit, new loans, and length of credit history.[6] Credit scores are therefore a clear summary measure of one's ability to obtain a credit card, and the amount of credit available to them. The difference in average scores is stark when looking at self-reported measures–those with low literacy report on average a credit score around 570, compared with 690 for medium literacy

5 Debit card ownership is defined as reporting one or more debit cards available to make purchases or a main bank account.

6 https://www.transunion.ca/what-affect-credit-score.

and 750 for high literacy. This may be driven by recall bias or measurement error, as results are much less exaggerated when using scores from the matched TransUnion data. In this case low-literacy respondents average scores of 730, compared with, 760 and 780 for medium- and high-literacy respondents, respectively. This seems to suggest that respondents with low literacy are severely under-estimating their credit scores, while those with high literacy are only slightly under-estimating.

Perhaps surprisingly, we find that low financial literacy is associated with the adoption of emerging technologies. For example, low-literacy respondents are more likely than high-literacy respondents to have completed a purchase or P2P transfer with a mobile app or digital currency in the past year, and are slightly less likely to use cash for P2P (*Figure 2*). Results from Henry et al. (2019) show that those with high literacy are more likely to have heard of Bitcoin but are less likely to own it. Specifically, Bitcoin ownership is about 4 percent among high-literacy respondents compared with 7 percent among their low-literacy counterparts. This type of result is consistent with other research–in particular, Lusardi et al. (2018) find correlations between poor financial management and mobile payment adoption among millennials. Taken on the face of it, these trends are disconcerting–for instance, Jonker and Kosse (Forthcoming) emphasize the need for financial literacy in ensuring advances in fintech can benefit those who otherwise may not know how to use the technology in a safe way.

4.2 Cash management

Henry et al. (2018) found that low-literacy respondents tended to withdraw similar amounts of cash to those with high literacy, but did so more often, suggesting a higher total withdrawal amount per month. Our findings from the 2017 SQ demonstrate common trends in cash usage (*Table 3*). Namely, individuals with lower levels of financial literacy tend to use and hold more cash than those with high financial literacy.

Low-literacy respondents make 2.7 ABM withdrawals per month on average, compared to high-literacy respondents, who make 2.1 withdrawals in the same time frame. They also tend to hold more cash on their persons and make more purchases in cash, which is unsurprising given that cash-intensive users will need to carry more cash for transactions and replenish their stock more often. Perhaps most strikingly, low-literacy respondents were also about three times more likely than high-literacy respondents to have held some of their cash in $100 notes (17 percent vs. 5 percent).

We note that high-income individuals tend to hold more cash than those with low income ($132 vs. $67). However, we noted previously that financial literacy tends to decrease with age. This suggests that aside from financial literacy, there may be other important mechanisms through which cash holdings increase, which we will discuss in further detail in section 5.

The 2017 SQ provides some possible reasons that low-literacy individuals may hold higher levels of cash (*Table 4*). For example, about a quarter reported obtaining cash from their employer in the past year, compared with 12 percent and 10 percent for medium- and high-literacy individuals, respectively. Further, low literacy was associated with holding cash to "control spending or help budget" or "save money outside a bank." These findings should not be indicative that only low-literate people use cash, however. For instance, high-literacy individuals were more likely to state they use cash for "emergencies or natural disaster preparedness."

4.3 Method of payment use at point-of-sale

Given the above observations that low financial literacy is associated with lower credit card adoption and higher cash holdings, it is unsurprising that those with lower literacy tend to complete more of their purchases using cash and less in credit, both in terms of the number and value of transactions (*Figure 3*). Specifically, those with low financial literacy complete 24 percent of their transactions (40 percent of value) using credit cards while high-literacy respondents are about twice as likely to use credit cards (47 percent of volume and 64 percent of value). This corresponds to a lower share of both cash and debit cards. For instance, 36 percent of transactions are completed using cash among those with low financial literacy compared with 30 percent among the highly literate. The share of value spent with cash similarly decreases from 20 to 13 percent. The trend is more pronounced for debit cards: 38 percent of volume among those with low financial literacy compared with 20 percent among those with high literacy[7] These trends persist when conditioning on the population of credit card owners, and after controlling for demographics and credit card characteristics.

Respondents were asked to rate methods of payment on a 5-point scale based on whether each is easy, costly, or secure to use. Those with low literacy tend to rate all methods of payment as easier to use, less costly, or more secure relative to their higher-literacy counterparts. Thus, to make comparisons we standardize by using relative measures of perceptions with cash as the baseline (*Figure 4*). We find that low-literacy respondents view debit and credit cards as easier to use, less costly, and more secure compared with their higher-literacy counterparts. This, combined with the fact that low-literacy respondents are more credit constrained, provide one possible demand-side reason for why those with lower levels of literacy use debit card more often at the point of sale.

5 Financial literacy, cash, and credit card adoption

The goal of this section is to conduct multivariate correlation analysis between financial literacy on cash demand in the context of the interplay between cash holdings and credit card adoption. Let Cashin, FL_i, and CC_i denote cash holdings, financial literacy, and credit card adoption, respectively, for respondent i. We undertake a linear regression analysis of the log of cash holding:

$$\log(Cash_i) \quad = \quad X_i\beta_{Cash} + \alpha_{Cash}FL_i + \delta_{Cash}\mathrm{CC}_i + \epsilon_i,$$

7 Value shares are nearly identical.

where X_i is a vector of explanatory variables and ϵ_i is the residual term. Since not all respondents have a credit card, we model credit card ownership with a probit regression:

$$Pr(CC_i = 1) \quad = \quad Pr(X_i\beta_{CC} + \alpha_{CC}FL_i + u_i > 0),$$

where u_i is a normally distributed error.

Table 7 provides results from these two regressions. We find that financial literacy appears uncorrelated with cash holdings when controlling for credit card ownership. Instead, variables that positively affect cash holdings include higher income, being born outside of Canada, and various reasons such as holding cash for emergencies and for budgeting purposes.[8] However, financial literacy is positively associated with credit card adoption, which in turn is a significant predictor of cash holdings. Using this model to predict the effect of financial literacy on cash holdings through credit card adoption could be problematic since we expect adoption to be endogenous. That is, those who prefer cash may be less likely to sign up for a credit card, while at the same time those who are not eligible for a credit card may hold more cash out of necessity. In other words, we expect there to be a degree of selection where ϵ_i and u_i are correlated. Future work will analyze the effect of credit card ownership on the relationship between cash holdings and financial literacy.

6 Conclusion

Based on the above analysis, some stories emerge about the low-literacy population. While we can't claim causation, financial literacy is shown to be a strong predictor of many aspects of payment behaviour. Low-literacy individuals are sur-

8 Kalckreuth et al. (2014) find that German respondents use cash to monitor their expenditures.

prisingly more likely to adopt emerging technologies including Bitcoin but are less likely to own a credit card. At the point-of-sale, they are more likely to use cash or debit instead of credit (even among credit card owners), make more trips to the ABM, and hold larger amounts of cash–specifically $100 bills.

Some demand- and supply-side factors are associated with low literacy which could explain some of these behaviours. For instance, low-literacy respondents are more likely to be paid by their employer in cash. On the other hand, low-literacy individuals' rate both debit and credit cards as easier to use, cheaper, and more secure compared to cash, but are less credit-intensive perhaps due to supply-side constraints: they have higher fees, lower limits, and fewer rewards.[9] They also have significantly lower credit scores and are more likely to revolve on their credit. These supply-side constraints are themselves functions of demand–in particular, past credit card use is considered when computing credit scores.

We note that when controlling for credit card ownership, financial literacy does not appear to be correlated with cash holdings. However, Ownership is both a predictor of high cash holdings and is correlated with high financial literacy, potentially introducing a degree of endogeneity in our model. This has the potential to skew our findings, and future work will more rigorously examine the role of credit card adoption in the relationship between financial literacy and cash holdings.

Future analysis should also focus on drawing causal inferences between financial literacy and cash usage. For instance, it may be that credit card owners tend to hold the same target amount of cash, but as they spend cash less often, they tend to hold more on average. Another explanation could be that, while we control for income in the model, we do not control for spending. Prelec and Simester (2001), for instance, find experimental evidence that using credit cards is associated with

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9 Kalckreuth et al. (2014) find that German respondents use cash to monitor their expenditures.

an increase in one's willingness to pay. Thus, it could be that the effect of credit card adoption is an increase in one's total expenditure rather than a decrease in cash holdings. Future analysis should also focus on differing measures of cash use (such as volume shares) and credit supply (such as credit card limit). Finally, financial literacy itself could be considered endogenous. For example, one's literacy could impact how they manage finances, and therefore how likely they are to obtain a credit card and/or obtain a high limit. On the other hand, using a credit card itself could produce a "learning by doing" effect whereby one gains financial knowledge through their mistakes and successes. Future work could investigate the use of instruments for financial literacy.

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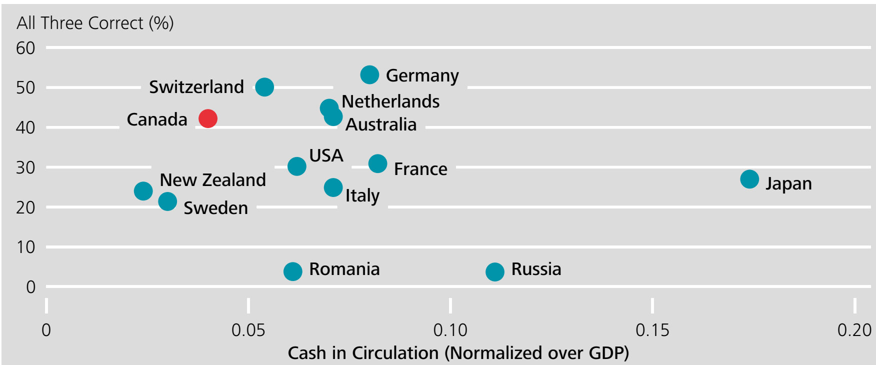
Financial literacy and cash in circulation: international comparison

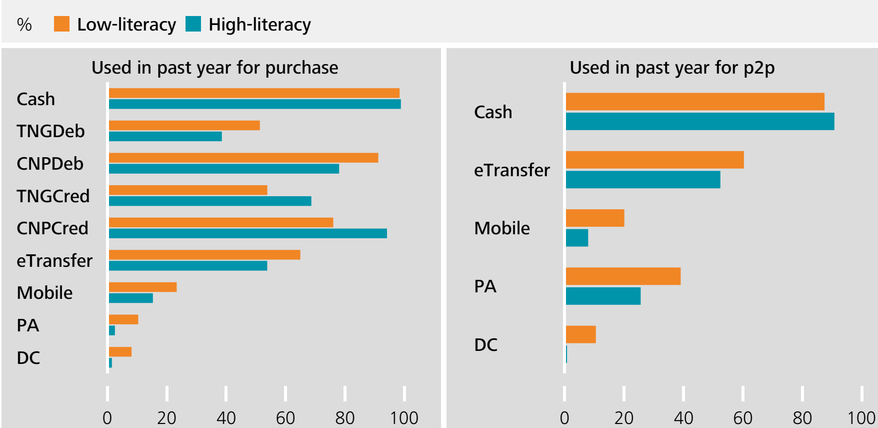
Figure 1



Notes: The vertical axis shows the percentage of respondents who answered all three financial literacy questions correctly, as defined in Table 2. Canadian numbers come from the 2017 MOP Survey. Other countries come from various studies, collected and summarized by Lusardi and Mitchell (2014). The horizontal axis shows the total value of cash in circulation (source: Bank of Canada) as a share of nominal GDP (source: IMF). Note that methodologies for measuring financial literacy sometimes differ across countries – see Lusardi and Mitchell (2014) for full details.

Payment adoption by financial literacy

Figure 2

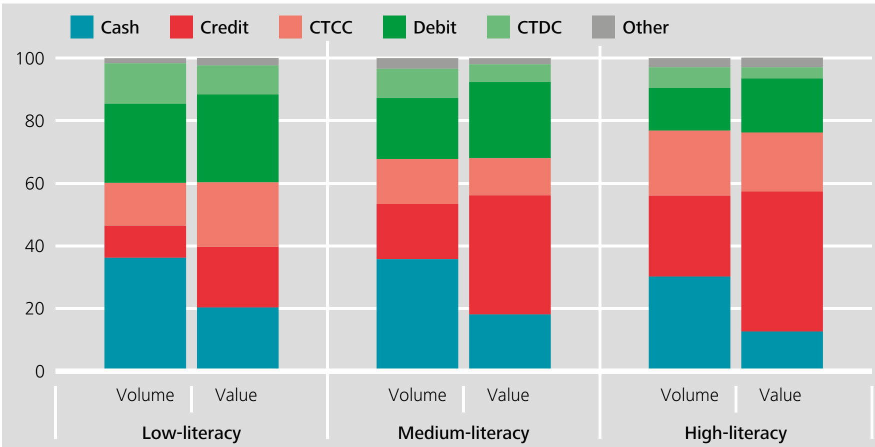


Notes: This figure shows the percentage of low- and high-literacy respondents who used each method of payment in the past year to make a purchase at a retailer or business (left) or a person-to-person transfer (right). TNG refers to the tap and go feature of a debit or credit card. CNP refers to the chip and pin feature of a debit or credit card. PA refers to an online payment account such as PayPal. DC refers to a digital currency such as Bitcoin.

Payment volume and value shares by financial literacy

Figure 3

Share %

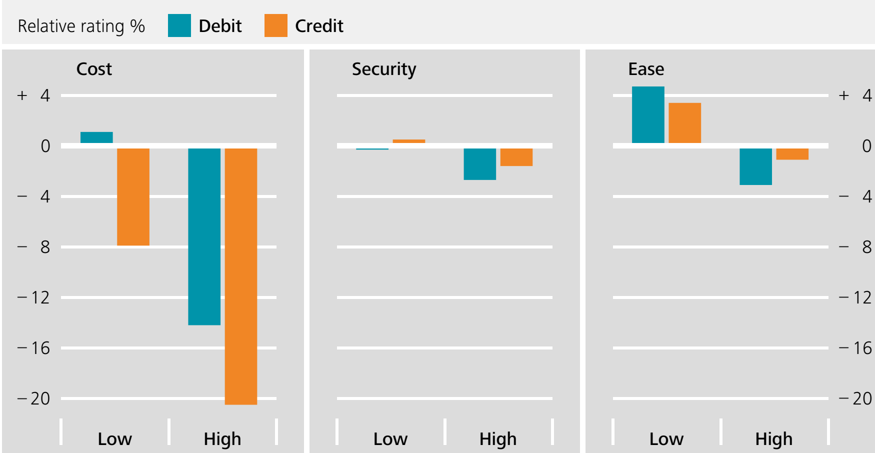


Notes: Volume measures the share of transactions made using each method of payment. Value measure the share of the value of these transactions by each method of payment. Results are shown by level of financial literacy.

Perceptions of debit and credit cards relative to cash

Figure 4

Relative rating %



Notes: Perceptions were measured on a 5-point scale with 1 being worst and 5 being best. For debit an credit cards, we average over "tap and go" and "chip and pin" ratings. The relative rating (y-axis) is measured as a method of payment's rating divided by the rating of cash minus 1, so that cash is normalized to 0. Thus, values greater than 0 imply a method is preferred to cash, while values smaller than 0 imply that cash is preferred.

Financial literacy questions

Table 2

Concept	Question	Response Options
Interest	Suppose you had $100 in a savings account and the interest rate was 2% per year. After 5 years, how much do you think you would have left in the account if you left the money to grow?	**More than $102** Exactly $102 Less than $102 Do not know
Inflation	Imagine the interest rate on yours savings account was 1% per year and inflation was 2% per year. After 1 year, how much would you be able to buy with this money in this account?	More than today Exactly the same **Less than today** Do not know
Risk	Please tell me whethere or not this statement is true or false: Buying a single company's stock usually prvodies a safer return than a mutual fund of stocks.	True **False** Do not know

Note: This table shows the \Big Three" nancial literacy questions included in the 2017 MOP Survey. Correct responses are highlighted in bold. The questions were developed by Lusardi and Mitchell (2011a).

Cash Use and Management

Table 3

	Cash volume share (%)	Cash holdings ($)	ABM with-drawals (# per month)	Holding $100 note (%)
OVERALL	33	105	2,3	9
AGE				
18-34	27	118	1,9	15
35-54	31	96	2,7	8
55+	19	104	2,2	5
EDUCATION				
High school	36	106	2,2	7
College	34	95	2,4	8
University	27	114	2,3	12
INCOME				
Less than $45K	44	67	2,1	6
$45K-$85K	32	99	2,4	8
$85K or more	28	132	2,4	10
GENDER				
Male	34	121	2,6	10
Female	32	89	2	7
FINANCIAL LITERACY				
Low	36	131	2,7	17
Medium	36	101	2,4	8
High	30	94	2,1	5

Note: Percent share of transactions made using cash, value of cash held in purse or wallet, number of monthly withdrawals, and percent of respondents holding a $100 note, by socio-demographic characteristics.

Reasons for holding cash Table 4

Literacy	P2P	Budget	Saving	Emergency	Employer
Low	25	28	19	31	26
Medium	32	22	14	36	12
High	30	15	12	43	10

Note: Respondents were asked to report if they ever hold cash for the following reasons: to give money to another person (**P2P**), to control spending or help budget (**Budget**), to save money outside of a bank (Saving), and for emergencies or natural disaster preparedness (**Emergency**). They were also asked if they had obtained cash from their employer in the past year (**Employer**).

Credit Card Characteristics Table 5

	Owns CC	Limit <2K	Revolver	Rewards	No annual fee
OVERALL	89	15	30	84	63
AGE					
18-34	81	31	32	87	56
35-54	92	14	40	79	62
55+	91	5	20	88	69
EDUCATION					
High school	83	18	32	84	69
College	93	16	35	81	61
University	94	10	24	88	58
INCOME					
Less than $45K	77	26	32	82	79
$45K-$85K	90	15	32	82	63
$85K or more	95	10	28	87	56
GENDER					
Male	87	16	29	86	61
Female	90	14	32	83	65
FINANCIAL LITERACY					
Low	79	25	47	80	64
Medium	87	18	34	79	65
High	95	8	20	90	59

Note: Percent share of respondents who report having one of the above credit card attributes.

Credit scores and financial literacy

Table 6

Literacy	% provided exact	Average score (self-reported)	% excellent (inexact)	Average score (TU match)	Employer
Low	14	569	24	734	26
Medium	13	694	39	759	12
High	18	747	56	782	10

Note: This table reports the percentage of MOP respondents who self-reported their exact score, average credit scores among these individuals, the percentage with self-reported "excellent scores" based on checkbox answers (see *Figure 6*), and average scores based on matches and imputations from the TransUnion dataset (see Appendix A.1).

Regression results of card ownership and cash holdings

Table 7.1

	Log-cash holdings	CC ownership
log(age)	-10.7991***	-0.4227*
log(age)2	1.5563***	0.0515*
Male	-	-
Female	-0.1687***	0.0190**
HS	-	-
College	0.1289	0.0473***
University	0.1352*	0.0477***
Unemployed	-	-
Employed full-time	0.0892	0.0622***
Employed part-time	0.1215	0.0039
Born in Canada	-	-
Not born in Canada	0.4032***	0.0208*
Rural	-	-
Urban	-0.0587	0.0211
<$45K	-	-
$45K-$85K	0.2639***	0.0147
$85K+	0.4229***	0.0490***
Low literacy	-	-
Medium literacy	0.0385	0.0171
High literacy	0.0038	0.0407***
Hold cash - emergencies	0.5653***	0.0224**
Hold cash - budgeting	0.4203***	-0.0247**
Hold cash - saving	0.1845**	-0.0206*
Hold cash - P2P	-0.017	-0.0019

Regression results of card ownership and cash holdings

Table 7.2

	Log-cash holdings	CC ownership
Credit score	0.006	0.0009***
Mail volume < 15	-	-
Mail volume > 15	0.0304	-0.0292**
Own credit card	0.3336***	
Observations	3008	3018

Note: Individuals with $0 in cash holdings are assumed to have $1. Baseline levels of variables are denoted by {* p < 0.1 ** p < 0.05 *** p < 0.01.

A Appendix

A.1 TransUnion Matching

The 2017 MOP was matched with TransUnion data to obtain information on credit scores, as only a fraction of respondents knew their exact score. The TransUnion dataset provides records of almost every credit-active consumer in Canada, but there is no identifying information in either the MOP or TransUnion dataset. Because of this, we match as closely as possible on several variables. Not all individuals are matched, so we perform fuzzy matching on fewer and fewer variables, trading off a loss in precision. Remaining unmatched observations are imputed using neighbouring FSAs. The full procedure is as follows:

1. Match on FSA, age, number of credit cards, bank network, financial institution, and credit limit. This results in 1558 unmatched MOP respondents over 50% of the population.
2. Match on everything except the bank network, on which an approximate matching is used. Another 300 MOP respondents are matched this way.
3. Match on everything except the number of credit cards respondents may no longer use some cards or forget the number of cards they own, leading to different answers in the two datasets. This creates 2239 matches, while 888 unmatched respondents remain.
4. Match on everything except FSA. 703 unmatched observations remain.
5. Match on FSA, age, and credit limit. 399 unmatched observations remain.
6. Match on everything except credit limit. 384 unmatched observations remain.
7. Match on FSA, age, and number of cards. This creates 2752 matches, while 375 unmatched respondents remain.
8. For the remaining 375 MOP respondents who are not matched to a credit score, we impute their score using the mean credit score by age group of all adjacent FSAs. If an individual resides in an FSA without neighbours their credit score is imputed as the mean of all credit scores within their age group.

Given matches are inexact, it is worth comparing them to MOP responses where possible. We expect the two measures to be correlated, and if one can be considered the "gold standard" then the difference between the two is a measure of bias. For those who provided their exact credit score, there is a positive correlation (0.44) between self-reported score and matched TransUnion score (*Figure 5*). However, treating TransUnion scores as the gold standard, there appears to be an average bias, as shown by the regression line being far from the 45-degree line we would expect. There is also much variation around this line, with lower TransUnion scores seemingly being measured with less precision on the MOP.

For those who provided their credit score in ranges, the story is much different, with most of individuals having good or excellent credit scores according to TransUnion regardless of their self-reported scores (*Table 8*). However, there is some correlation: the likelihood having an excellent credit score based on TransUnion matching is higher for those with higher self- reported scores, and those who self-report very poor scores are indeed more likely to have poorer TransUnion scores. The mismatch here between self-reported and TransUnion scores could suggest that MOP respondents are not basing their choices on the provided credit score bins (*Figure 6*).

A.2 Mintel matching

We also match MOP respondents to the number of solicitations sent to individuals by credit card companies. These offers often contain invitations to apply for new cards, collect rewards points, or increase their credit limits. We extract the total number of pieces for direct mail offerings and email offerings from Mintel Comperemedia.

We begin by aggregating all campaigns sent to a given demographic group as defined by Mintel (e.g. aged 26 to 30, income $50,000 to $74,000, Ontario). This allows us to total all campaigns sent to an individual within each group. Next, we clean the Mintel dataset so that variables are consistent with MOP variables for matching. Note that Mintel and MOP records income levels in different tiers. We then mean across these aggregated MOP demographics to obtain the final cleaned Mintel dataset.

Matching occurs on the demographic variables available to us: age, income, number of household members. A deterministic match is performed on age, income, and province (since these are recorded in tiers, there is less chance of response error resulting in incorrect responses), though a probabilistic match is performed on FSA and household members. If multiple campaigns are matched to the same MOP respondent, we average these to obtain the number of solicitations received by that respondent. If no match is found, we impute for the number of solicitations using results from adjacent FSAs, then increase our search to the CMA level (aggregations of several FSAs). The full matching algorithm is as follows:

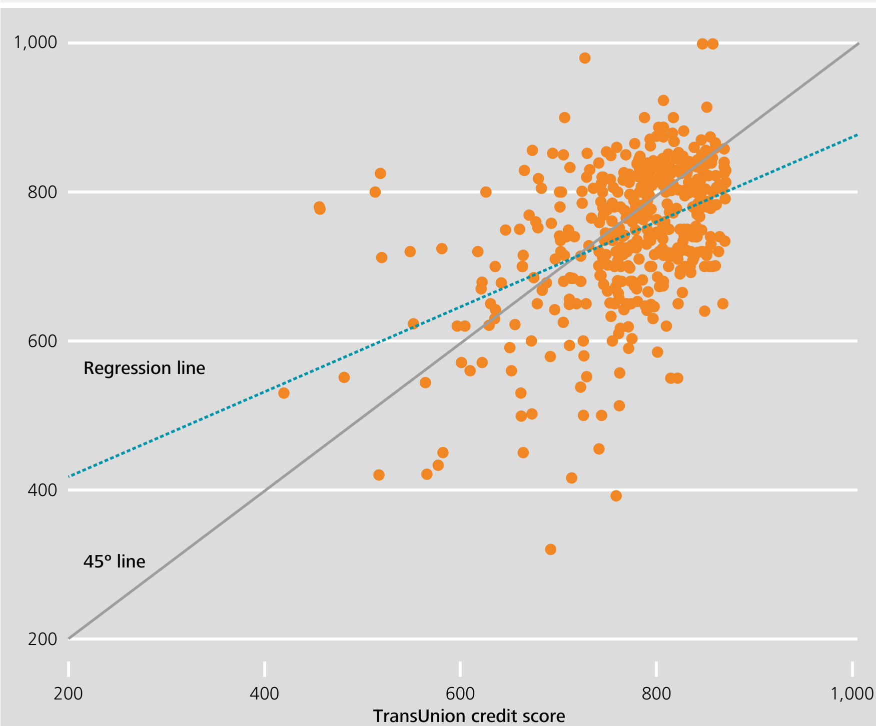
1. Match on age, income, number of household members, and FSA.
2. Impute for credit card solicitations using matched results from adjacent FSAs, using age, income, and number of household members.
3. Match on age, income, number of household members, and CMA.
4. Impute for credit card solicitations using matched results from adjacent CMAs, using age, income, and number of household members.
5. Match on age, income, number of household members, and FSA, using solicitation campaigns from adjacent years 2016 and 2018.
6. Impute for credit card solicitations using matched results from adjacent FSAs in 2010, using age, income, and number of household members.
7. Match on age, income, number of household members, and CMA, using solicitation campaigns from adjacent years 2016 and 2018.
8. Impute for credit card solicitations using matched results from adjacent CMAs in 2016 and 2018, using age, income, and number of household members.

A total of 3,024 MOP respondents are assigned a number of email solicitations this way. Matched results indicate that most of email solicitations are targeted towards younger, low literacy respondents with a middle-class income (*Table 9*).

Results of credit score matching

Figure 5

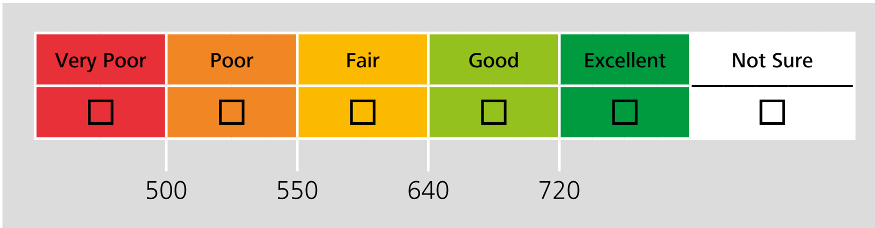
Self-reported credit score



Source: 2017 MOP, TransUnion.

Credit score breakdown in MOP survey questionnaire

Figure 6



Note: Credit score bins in the 2017 Methods-of-Payment Survey Questionnaire. A score of 720 or above is classied as excellent, while a score of under 550 is subprime.

Transunion matches Table 8

	Very poor (≤500)	Poor (500-550)	Fair (550-640)	Good (641-720)	Excellent (≥720)
Very poor (≤500)	0%	8%	27%	23%	42%
Poor (500-550)	5%	0%	6%	32%	56%
Fair (550-640)	1%	2%	10%	33%	54%
Good (641-720)	0%	1%	4%	17%	78%
Excellent (≥720)	0%	1%	2%	7%	91%
Total	0%	1%	3%	13%	82%

Note: Comparison of binned MOP credit scores versus matched TransUnion credit scores.

Mintel Offerings Table 9

	Low	Medium	High
OVERALL	7,27	7,24	6,96
AGE			
18-34	8,32	9,24	10,83
35-54	5,49	6,16	5,53
55+	7,13	6,32	5,74
INCOME			
<$45K	6,88	7,48	7,45
$45K-$85K	7,29	6,91	6,32
$85K+	8,08	7,23	7,24

Note: Counts of annual credit card offers by financial literacy and demographics.
1 Kalckreuth et al. (2014) find that German respondents use cash to monitor their expenditures.

Hiroshi Fujiki, Kiyotaka Nakashima
Cash Usage Trends in Japan: Evidence Using Aggregate and Household Survey Data[1]

Hiroshi Fujiki
Chuo University

Abstract

We examine the trends in cash usage in Japan and its substitution with noncash payment methods, such as credit cards and electronic money, using both aggregate and individual household survey data. We find that cash hoarding accounts for as much as 42% of total cash circulation in Japan. Behind this finding lies an unstable semi-log cash demand function after the late 1990s and a stable log-log

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cash demand function from 1995 to 2015. We also find that electronic money users tend to have smaller cash holdings than cash only users for day-to-day transaction values of less than 5,000 yen; credit card users choosing credit cards for both day-to-day transactions and regular payments tend to have smaller cash holdings compared with cash only users for day-to-day transactions who do not use credit cards for regular payments for all ranges of day-to-day transaction values.

1. Introduction

Following the global financial crisis, many researchers have pointed out that currency usage has shown a surprising recovery in most advanced economies. For example, during the period from 2002 to 2017 (*Figure 1*), the currency to gross domestic product (GDP) ratio increased from 14% to 19% in Japan, from 6% to 8% in the US, and from 3% to 10% in the Eurozone. Important exceptions to this trend are Canada, where the currency to GDP ratio has remained stable, and Sweden, where the currency to GDP ratio has been falling.[2] It is puzzling to note that the ratio of currency in circulation to nominal GDP increased despite the advances in noncash means of payments in Japan, the US, and the Eurozone, which would induce people to choose to pay by credit cards or debit cards, rather than cash.

Figure 1 also indicates that currency to GDP ratios accelerated following the global financial crisis in Japan, the US, and the Eurozone. However, the Japanese currency to GDP ratio was 14% in 2002, but only 6% in the US and just 3% in the Eurozone. Clearly, Japan is an advanced economy with a sophisticated banking system. Why was the Japanese currency to GDP ratio already so high in 2002?

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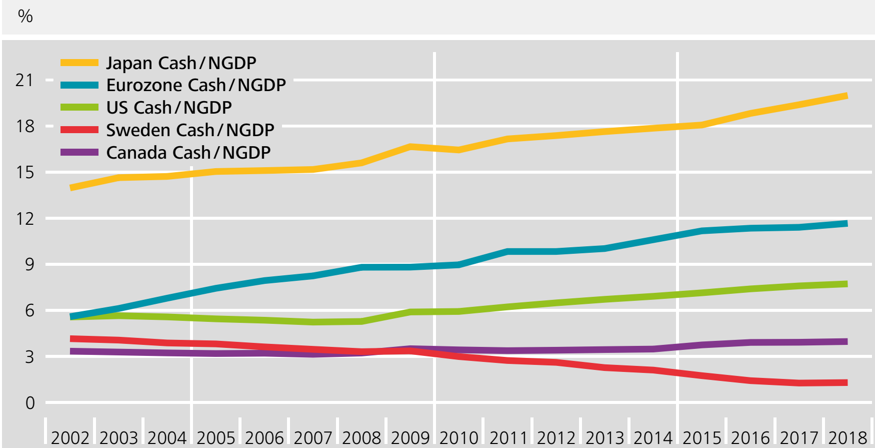
2 See Jobst and Stix (2017) and Goodhart and Ashworth (2017) for cross-country evidence. See Judson (2017) and Riksbank (2018) for the US and Swedish experiences, respectively. Jiang and Shao (2014) provided a model where the total demand for money may not decrease even if cash plays a diminishing role in transactions.

Currency to GDP ratio in Japan, US, Eurozone, Canada and Sweden

Figure 1



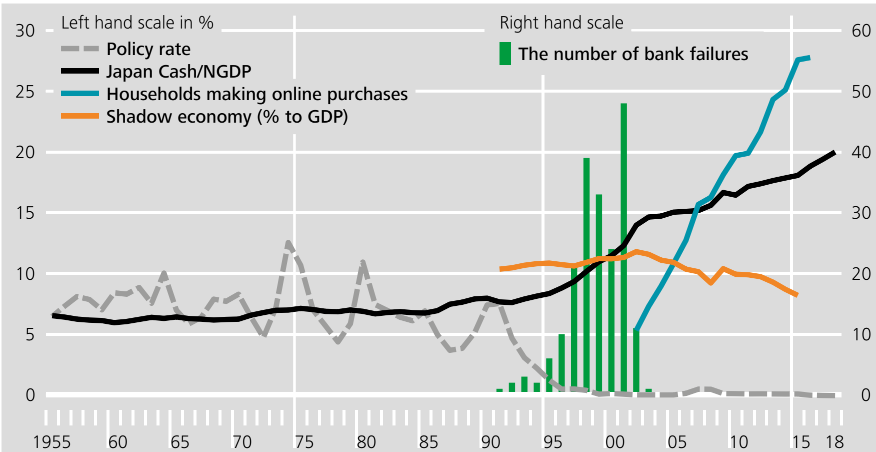
Sources: Bank of Japan, Cabinet Office of Japan, European Central Bank, Board of Governors of the Federal Reserve System, Bank of Canada, International Monetary Fund, and author's calculations.

To appreciate this finding better, the solid line in *Figure 2* plots the long-run trend in the Japanese currency to GDP ratio from 1955 to 2017. By the middle of the 1990s, the currency to GDP ratio was about 6–8%, but since then it has increased steadily. In addition, in 1995 the Bank of Japan (BOJ) became the first advanced-economy central bank since World War II to set an effective zero-lower bound for the nominal interest rate, as depicted by the dashed line in *Figure 2*. This suggests that we need to pay close attention to the factors unique to Japan prior to the global financial crisis, to understand the reasons underpinning the steady increase in the currency to GDP ratio in Japan observed since 1995.

Why did the ratio of currency in circulation to nominal GDP increase despite the advances in noncash means of payment in Japan? We argue that the cash demand for hoarding was so strong that it outweighed the negative effect of the substitution to noncash means of payment for day-to-day payments. To support our argu-

Currency GDP ratio and policy interest rate

Figure 2



Sources: Bank of Japan, Cabinet office, Deposit Insurance Corporation of Japan, Medina and Schneider (2018), and Ministry of Internal Affairs and Communications of Japan. Notes: Japanese policy interest rates use the following series: 1955–1959, basic discount and loan rate; 1960–1984, call rate, collateralized overnight, average; 1985–2017, call rate, uncollateralized overnight, average. Nominal GDP for each year uses the following series: 2011 SNA data for 1980–2017, extended using the annual growth rates in 1968 SNA data for 1955–1979, 2017 data use first quick estimates. The number of bank failures is from the Deposit Insurance Corporation of Japan. The size of the shadow economy is from Medina and Schneider (2018). The percentage of households making online purchases is from the White Paper on Information and Communications in Japan 2017, and Ministry of Internal Affairs and Communications of Japan.

ment, we examine the trends in cash usage in Japan with a special emphasis on cash hoarding and its substitution with electronic means of payment, such as credit cards and electronic money, using both aggregate data since 1955 and household survey data after 2007. First, we begin by illustrating the steady increase in cash in circulation in Japan, especially after 1995. Second, after listing the possible reasons for this increase, we examine the extent to which this increase could be attributable to the increase in cash hoarding (so-called mattress deposits). Third, we examine whether there were any structural breaks in the Japanese aggregate cash demand function after the mid 1990s. In particular, we test whether the income, semi-log, and log-log interest rate elasticity of aggregate cash demand changed consistently with the acceleration in cash demand. Fourth, we provide estimates of the decrease in cash holdings for day-to-day one-off payments arising from the substitution of cash with credit cards and electronic money using the household survey data from Fujiki (2019), which is based on Fujiki and Tanaka (2018a).

Our main findings are as follows. First, our analysis using aggregate data suggests that cash hoarding could account for as much as 42% of the total cash in circulation in Japan. Second, assuming a semi-log cash demand function, there is a significant structural change in the parameters of the Japanese cash demand function, especially its interest rate semi-elasticity in the late 1990s or early 2000s. If we instead assume a log-log cash demand function, there are no structural changes in the parameters of the cash demand function, suggesting that its implied interest rate semi-elasticity, defined as the interest rate elasticity divided by the interest rate, became very large in the late 1990s and early 2000s. Third, we find that electronic money users tend to have smaller cash holdings than cash only users for day-to-day transaction values of less than 5,000 yen. Fourth, we find that credit card users choosing credit cards for both day-to-day transactions and regular payments tend to have smaller cash holdings compared with cash only users for day-to-day transactions who do not use credit cards for regular payments for all ranges of day-to-day transaction values. Finally, our back-of-the-envelope calculations of the maximum impact of possible decreases in cash demand for daily one-off payments on the substitution from cash to noncash payment methods may not be so large, and at most 0.4% of the total cash in circulation in 2017 in Japan.

Using these findings to forecast the trends in cash usage in Japan, we argue that the BOJ should be more concerned about the decline in cash hoarding, for example, because of the increase in the policy interest rate in the future, than any substitution of cash for credit cards in daily transactions. An important reservation is that our evidence concerning the substitution of cash for noncash payments implicitly relies on the technology available in the period 2007–2017. Of course, it would be possible to further reduce the demand for cash for person-to-person (P2P) transactions if some new technology were to prevail, say, P2P electronic bank transfers using a cellphone QR code app developed by large Japanese banks.

Let us briefly touch on the Japanese demand for cash literature. Empirical studies on the demand for cash as financial technologies evolve include Fujiki and Tanaka (2018a, 2018b, 2014) and Fujiki (2019) who used the Survey of Household Finance, while Nakata (2012) employed a panel data set and found that electronic money users held as much cash as nonusers. Related studies for other countries are reported in Fujiki (2019).

The remainder of the paper is organized as follows. Section 2 reports our aggregate data evidence. Section 3 discusses our evidence using household survey data. Section 4 concludes the paper.

2. Aggregate data Evidence

2.1. Aggregate cash holdings

Figure 2 shows the ratio of currency in circulation to nominal GDP in Japan (solid line) and Japanese policy interest rate (dashed line). As shown, the ratio of currency to nominal GDP was stable up until 1995 (averaging 6.8% from 1955 to 1995), but afterwards the ratio increased steadily, reaching 19% by 2017. *Figure 2* also shows that the Japanese policy interest rate has remained around zero since 1995 (averaging just 0.14% from 1996 to 2017). Several factors possibly drove the accelerating demand for currency well above the nominal economic growth rate in Japan after 1995; however, apart from this, policy interest rates were subsequently very low. From 1997 to 1998, Japan experienced a banking crisis (orange bars in *Figure 2*), which saw the removal of the blanket guarantee for bank time deposits in 2003 and bank ordinary deposits in 2005. While the major banks had regained much of their financial strength by 2006, the BOJ began its Quantitative and Qualitative Easing Program in April 2013 and enacted a negative interest rate policy in January 2016.

Note that the ratio of currency in circulation to nominal GDP increased despite the rapid increase in online purchases in Japan, which would induce people to choose to pay by credit cards rather than cash. According to White Paper on Information and Communications in Japan 2018[3] the percentage of households making online purchases increased from 5.3% in 2002 to 27.8% in 2016, as indicated by the solid blue line in *Figure 2*.

In addition to these monetary factors, the rapid growth of foreign tourism in Japan after 2014 may also relate to the increase in cash demand. Some researchers also suggest that the introduction of a social security and tax number system (the My Number system) in 2016 may also have increased the demand for cash because information on financial institution accounts under this new system is passed on to the authorities if an account holder has a My Number. As some wealthy people may prefer not to disclose their financial asset holdings to the government for many reasons, they may well have withdrawn bank deposits in exchange for cash and then retained the cash in safe deposit boxes. Alternatively, did the ratio of currency in circulation to nominal GDP increase because of an expansion of the shadow economy, rather than cash hoarding? However, Medina and Schneider (2018) show that the size of the shadow economy in Japan remained stable from 1991 to 2015, as the dotted blue line in *Figure 2* shows. These episodes suggest that cash hoarding, especially in the form of 10,000 yen notes (the largest denomination note), may be prevalent in Japan. We present an estimate of possible cash hoarding in Japan in the following subsection.

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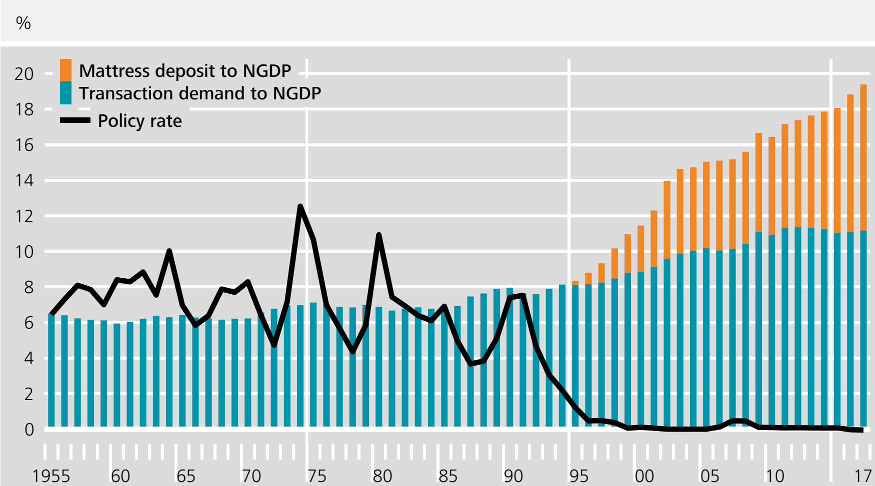
3 See the website of the Ministry of Internal Affairs and Communications of Japan for the full text of the White Paper on Information and Communications in Japan, 2018. http://www.soumu.go.jp/johotsusintokei/whitepaper/eng/WP2018/2018-index.html (accessed February 1, 2019).

2.2. Cash hoarding

We update the estimates of cash hoarding by Fujiki and Tomura (2017) using the method proposed by Otani and Suzuki (2008). Otani and Suzuki (2008) assumed that people only use 10,000 yen notes for cash hoarding, and that the transaction demand for 1,000 yen notes (the major means of day-to-day one-off transactions) and 10,000 yen notes are proportional to each other. Hence, they assume that the transaction demand for 10,000 yen notes will grow at the same rate as that for 1,000 yen notes. Otani and Suzuki (2008) set 1995 as the base year in which there was no cash hoarding in Japan, and estimated cash hoarding as the difference between the total number of 10,000 yen notes in circulation and the estimated transaction demand for 10,000 yen notes. *Figure 3* illustrates the estimates of cash hoarding in Japan using this method, with 8.2% of the 19.4% ratio of currency in circulation to nominal GDP in 2017 categorized as cash hoarding. In other words, some 45 trillion of the 106 trillion yen currency in circulation in Japan in 2017, or 42% of the total cash in circulation, could result from cash hoarding.

Cash hoarding in Japan

Figure 3



Sources: Bank of Japan, Cabinet Office of Japan, and author’s calculations.

2.3. Long-term cash demand function

In this section, we examine the long-term relationship between cash, nominal GDP, and interest rates in Japan using standard time-series analysis. The main question is whether the income (GDP) elasticity of cash demand is greater than unity after 1995, as suggested by *Figure 2*, and whether the interest rate elasticity of cash demand is stable after 1995. Behind this observation lies the fact that the BOJ has kept the short-term interest rate close to zero since 1995. In this regard, several economists have examined whether Japan has been in a liquidity trap, in the sense that the demand for cash has increased substantially. For this purpose, these studies often estimate two types of money demand functions: either a semi-log money demand function as in equation (1) or a log-log money demand function as in equation (2):

$$(1) \qquad \ln\left(\frac{Money\ \ stock}{PGDP}_{t}\right) = a0 + a1\ln(RGDP_t) + a2(Interest\ \ rate_t) + \varepsilon_{1t},$$

$$(2) \qquad \ln\left(\frac{Money\ \ Stock}{PGDP}_{t}\right) = b0 + b1\ln(RGDP_t) + b2ln(Interest\ \ rate_t) + \varepsilon_{2t},$$

where PGDP is the GDP deflator and RGDP is real GDP.

For example, Nakashima and Saito (2012) and Miyao (2002, 2005) both specified M1 (the sum of cash and demand deposits) as the money stock and the nominal overnight call rate as the interest rate to estimate the interest rate elasticity in Japan using equations (1) and (2) to identify any structural breaks in the demand function after 1995. Miyao (2002, 2005) set the income elasticity of M1 (a1 and b1) to one, whereas Fujiki and Watanabe (2004) used cross-sectional data across Japanese prefectures to set its value. Both studies also assumed that the income elasticities were constant and tested whether the interest rate elasticities increased substantially after 1995. Elsewhere, Nakashima and Saito (2012) examined the Japanese money demand function assuming both unitary and nonunitary income elasticities. In this paper, we extend this literature to estimate real banknote demand rather than real M1 demand in Japan as in Fujiki and Tomura (2016). We estimate equations (1) and (2) using cash as a proxy for the money stock. In doing so, we use bootstrap procedures that take into account small-sample bias in testing the null hypothesis of no cointegration against the alternative hypothesis of cointegration with breaks, in testing the null hypothesis of parameter constancy against the alternative of structural changes in parameters, and in estimating the confidence intervals of currency demand functions following Nakashima and Saito (2012), Appendix A1 to A3. See also Nakashima (2019) for details on the estimations.

Table 1 reports the mean, standard error (s.e.), minimum, maximum, and number of observations (N) of the variables of interest. Specifically, lncr is the log of cash in circulation deflated by PGDP, and Lnyr is the real GDP for the calendar year.[4] Policyrate is Japanese policy interest rates.[5] Lnpolicyrate is the log of policyrate.

Summary statistics Table 1

	Mean	S.E.	Minimum	Maximum	N
lncr	9,967	1,055	7,920	11,446	61
lnyr	12,415	0,756	10,650	13,157	61
policyrate	4,570	3,612	0,001	12,539	61
lnpolicyrate	0,273	2,567	-7,195	2,529	61

Note: S.E. – standard error.

4 Real GDP in 2017 are first estimates, real GDP data from 1980 to 2016 use the 2011 National Accounts of Japan (SNA) database final estimates, and real GDP data from 1955 to 1979 are estimates from applying the annual growth rates in the 1968 SNA database to the 1980 data.
5 The policy rate uses the following series: the basic discount and loan rate from 1955 to 1959, the call rate (collateralized overnight, average) from 1960 to 1984, and the call rate (uncollateralized overnight, average) from 1985 to 2017.

The sample period is from 1955 to 2015; thus, we have 61 observations because policyrate takes negative values after 2016 because of the BOJ's introduction of the negative interest rate policy in January 2016.

Before examining the income elasticity and interest rate elasticity of cash demand, we establish the existence of a unit root and a cointegrating relationship for cash, a scale variable, and interest rates. We first conduct unit root tests for each of the variables: the log of cash in circulation (lncr), real GDP (Lnyr), the level of the policy rate (Policyrate), and the log of the policy rate (Lnpolicyrate). We perform conventional tests including the augmented Dickey–Fuller and Phillips–Perron tests, and confirm that each variable has a unit root.

To establish the existence of a long-run relationship between cash, real GDP, and the policy rate, we apply Gregory and Hansen's (1996) test to equations (1) and (2) in *Table 2*. The null hypothesis is no cointegration and the alternative hypothesis is cointegration with breaks. We reject the null hypothesis of no cointegration for

Residual-based Tests for Cointegration with Regime Shifts: (1955-2015) Table 2

	Test Statistics		5% c.v.		
			Asymptotic	Bootstrap	
	Semilog	Log-log		Semilog	Log-log
Inf-ADF	-6,16	-6,27	-5,50	-5,75	-6,61
Inf-Zt	-5.85**	-6,33	-5,50	-5,67	-6,75
Inf-Zα	-45.80**	-47,97	-58,33	-42,18	-52,13

1. Tests are based on the regime shift model proposed by Gregory and Hansen (1996).
2. Asymptotic critical values are from Gregory and Hansen (1996).
3. Bootstrap critical values are computed from 5,000 replications under the null hypothesis of no cointegration.
4. For Inf-ADF, the lag length is selected using the t-test in Gregory and Hansen (1996).
5. * and *** indicate the 10% and 1% levels of significance for the bootstrap tests, respectively.

semi-log equation (1) at the 5% level of significance based on the critical values of the bootstrap distribution constructed by Nakashima and Saito (2012). For log-log equation (2), we also reject the null hypothesis at the 10% level of significance based on the critical values of the bootstrap distribution.

Given the rejection of the null hypothesis of no cointegration for both equations (1) and (2), we conduct parameter instability tests for all parameters (hereafter, we call this test the pure structural change test) and for one of the three parameters in the cash demand function (hereafter, we call this test the partial structural change test). We assume that the timing of a structural break is treated as unknown and adopt the Sup-F test based on the largest F-Statistics in the middle-70 percent of the full sample. *Table 3* reports the results of the parameter instability tests. The left panel shows the test results based on fully modified OLS (FMOLS) and the right panel shows the test results based on dynamic OLS (DOLS), where k is the number of leads and lags in estimating DOLS.

Tests for Parameter Instability of Currency Demand Equations Table 3

Fully Modified OLS (1955-2015)					
	Test Statistics		5% c.v.		
			Asymptotics	Bootstrap	
Sup F	Semilog	Log-log	Semilog	Log-log	
(1)	2817** (1998)	259,3 (1964)	17,3	2215	936,3
(2)	22,34 (1974)	16,47 (2002)	10,75	61,8	31,55
(3)	21,33 (1974)	16,36 (2002)	10,71	63,61	31,43
(4)	2105*** (1998)	18,25 (1972)	9,98	1067	50,41

Dynamic OLS (1955-2015)					
k=1	Test Statistics		5% c.v.		
			Asymptotics	Bootstrap	
Sup F	Semilog	Log-log	Semilog	Log-log	
(1)	26.57** (2001)	33,73 (2001)	17,3	23,89	39,73
(2)	18,62 (1995)	24,36 (1997)	10,75	20,54	30,4
(3)	18.71* (1995)	24,43 (1997)	10,71	19,27	27,82
(4)	24.39*** (1996)	86,99 (2001)	9,98	12,41	98,77

k = 2	Test Statistics		5% c.v.		
			Asymptotics	Bootstrap	
Sup F	Semilog	Log-log	Semilog	Log-log	
(1)	40.30** (2000)	41,54 (2000)	17,3	38,43	63,4
(2)	30,2 (1998)	28,94 (1996)	10,75	46,01	49,24
(3)	30,32 (1998)	29,00 (1996)	10,71	43,71	47,68
(4)	39.78*** (1996)	74,51 (2002)	9,98	31,54	87,71

1. Tests are based on the fully modified OLS and the dynamic OLS proposed by Hansen (1992) and Stock and Watson (1993), respectively.
2. Asymptotic critical values from Kuo (1998) for a partial structural change and Hansen (1992) for apure structural change.
3. Bootstrap critical values are from 5,000 replications under the null hypotheses of parameter constancyusing the sieve bootstrap proposed by Chang et al. (2006).
4. In each panel, the first row, denoted (1), comprises tests of the entire cointegrating vector, the second row (2) gives tests of the intercept, the third row (3) gives tests of the coefficient on RGDP, and the fourth row (4) gives tests of the coefficient on Interest Rate.
5. Data points with the largest F-statistics are in parentheses.
6. ** and *** indicate the 5% and 1% levels of significance for the bootstrap tests, respectively.

For semi-log equation (1), we find evidence for pure structural change in 1998, 2000, or 2001 based on the 10% critical values of the bootstrap distribution constructed by Nakashima and Saito (2012). We also find evidence for partial structural changes in the semi-log interest rate elasticity of cash demand in 1996 or 1998 based on the 10% critical values of the bootstrap distribution in both estimation methods. Overall, the test statistics for pure structural changes and partial structural changes suggest that there are pure structural changes in the late 1990s or early 2000s, which could be associated with the partial structural changes in the semi-log interest rate elasticity of currency demand in those periods. In contrast, for log-log equation (2), we find no evidence for pure structural changes and partial structural changes.

Using these results, we estimate the cointegration coefficients using FMOLS and DOLS before and after the pure structural changes using semi-log equation (1). For

Parameter Estimates of Currency Demand Equations Table 4

Fully Modified OLS (1955-2015)

	Period	95% C.I.	Constant	RGDP	Interest Rate
Semilog	1955–2015		-3,673	0,949	-0,096
		Asymptotic	(-1.302, -6.045)	(0.768, 1.129)	(-0.133, -0.060)
		Bootstrap	(-8.149, 8.096)	(0.402, 1.286)	(-0.326, -0.044)
	1955–1997		-5,586	1,06	-0,018
		Asymptotic	(-5.144, -6.442)	(1.014, 1.113)	(-0.022, -0.014)
		Bootstrap	(-6.716, -4.845)	(0.991, 1.137)	(-0.028, -0.010)
	1998–2015		-59,13	5,199	-0,394
		Asymptotic	(-77.63, -52.31)	(4.673, 6.609)	(-0.744, -0.048)
		Bootstrap	(-120.4, 25.60)	(-0.106, 10.72)	(-9.175, 0.026)
Log-log	1955–2015		-4,64	0,993	-0,115
		Asymptotic	(-6.876, -2.404)	(0.814, 1.172)	(-0.166, -0.065)
		Bootstrap	(-8.998, -1.652)	(0.738, 1.462)	(-0.192, -0.040)

Dynamic OLS (1955-2015)

k = 1	Period	95% C.I.	Constant	RGDP	Interest Rate
Semilog	1955–2015		-3,629	0,952	-0,091
		Asymptotic	(-3.739, -3.520)	(0.944, 0.960)	(-0.093, -0.090)
		Bootstrap	(-21.37, 15.75)	(0.378, 1.513)	(-0.175, -0.041)
	1955–1997		-4,487	0,994	-0,045
		Asymptotic	(-4.521, -4.453)	(0.992, 0.997)	(-0.046, -0.044)
		Bootstrap	(-6.519, -2.552)	(0.790, 1.231)	(-0.067, -0.033)
	1998–2015		-37,95	3,574	0,336
		Asymptotic	(-44.52, -30.38)	(3.050, 4.098)	(0.249, 0.423)
		Bootstrap	(-44.61, -31.29)	(-5.730, 14.08)	(-6.242, 7.776)
Log-log	1955–2015		-5,130	1,041	-0,107
		Asymptotic	(-5.254, -5.006)	(1.032, 1.051)	(-0.114, -0.112)
		Bootstrap	(-8.602, -2.251)	(0.849, 1.294)	(-0.169, -0.042)

k = 2	Period	95% C.I.	Constant	RGDP	Interest Rate
Semilog	1955–2015		-3,764	0,964	-0,094
		Asymptotic	(-3.891, -3.636)	(0.955, 0.974)	(-0.095, -0.093)
		Bootstrap	(-26.38, 22.76)	(0.173, 1.889)	(-0.146, -0.051)
	1955–1997		-4,333	0,982	-0,045
		Asymptotic	(-4.483, -4.183)	(0.973, 0.991)	(-0.049, -0.041)
		Bootstrap	(-5.498, -3.504)	(0.792, 1.229)	(-0.058, -0.039)
	1998–2015		-32,53	3,132	1,886
		Asymptotic	(-46.52, -18.54)	(2.036, 4.228)	(1.256, 2.516)
		Bootstrap	(-66.60, 4.234)	(-2.106, 5.292)	(-5.248, 7.596)
Log-log	1955–2015		-5,233	1,048	-0,113
		Asymptotic	(-5.333, -5.134)	(1.041, 1.056)	(-0.114, -0.112)
		Bootstrap	(-8.602, -2.251)	(0.849, 1.294)	(-0.169, -0.042)

1. The estimation method employs the fully modifed OLS and the dynamic OLS proposed by Phillips and Hansen (1990) and Stock and Watson (1993), respectively.
2. 95% C.I. is the 95% confidence interval.
3. Asymptotic and bootstrap are the asymptotic and bootstrap confidence intervals, respectively. The bootstrap confidence intervals employ the sieve bootstrap proposed by Chang et al. (2006).

log-log equation (2), we use the full sample period because we find no evidence for pure structural change and partial structural change. *Table 4* details the results from FMOLS (left panel) and those from DOLS (right panels, where k is the length of lags and leads) for equations (1) and (2). In this table, we report point estimates for the cointegration coefficients, their asymptotic confidence intervals, and bootstrap confidence intervals following Nakashima and Saito (2012). Regarding the results for equation (1), the point estimates before the pure structural changes are reasonably robust with respect to the choice of estimation method. However, the point estimates and bootstrap confidence intervals after the pure structural changes vary significantly depending on estimation method. The results indicate the difficulty of approximating a Japanese cash demand function by fitting two linear semi-log cash demand functions before and after the pure structural changes around the end of the 1990s and early 2000s. In contrast, regarding the results for log-log equation (2), the point estimates are robust with respect to the choice of estimation method. The results suggest that the income elasticity of cash demand is about 1, and the interest elasticity of cash demand is about –0.1. If we divide the interest rate elasticity obtained from a log-log cash demand function by the policy interest rate, we can approximate the conventional semi-log interest rate elasticity of cash demand function (hereafter, implied interest rate semi-elasticity). The stable log interest rate elasticities lead to extremely small values of the implied interest rate semi-elasticities after the mid 1990s, especially around 2001 to 2006, when the BOJ conducted the first round of quantitative easing, from 2001 to 2006. For example, the implied interest rate semi-elasticity obtained by FMOLS was −153.333 in 2005, when the call rate was 0.00075%, and fell to –0.243 in 2007. After the introduction of comprehensive easing in 2010 and quantitative and qualitative easing in 2013, the implied semi-elasticities increased again to around −1.5 in 2015. Behind these relatively small changes in semi-elasticities compared with the changes from 2001 to 2006 lies the fact that the BOJ started paying interest on excess reserve balances in 2008, and the policy rate at that time was well above zero until the introduction of the negative interest rate policy in 2016.

In summary, if we assume a semi-log cash demand function as per equation (1), the parameter estimates of the income elasticities of the cash demand functions before the pure structural changes are reasonably stable around one. However, there is a partial structural change in the semi-log interest rate elasticity of cash demand in 1996 or 1998. This is broadly consistent with the assumption made by Otani and Suzuki (2008), who set 1995 as the base year marking the beginning of cash hoarding in Japan. If we instead assume a log-log cash demand function as per equation (2), there is no evidence for pure structural change or partial structural change, and the long-run income elasticity of the demand for cash is one. However, the implied interest rate semi-elasticity of cash demand takes extremely small negative values, especially during the period of the first round of quantitative easing from 2001 to 2006. Overall, an accelerating growth rate in the demand for cash that exceeds the nominal economic growth rate after the mid 1990s could be explained by a combination of a stable unitary income elasticity of cash demand and very large implied interest rate semi-elasticity of cash demand in the low interest rate period.

The long-run stability of M1 demand has also been the subject of investigation in many other economies. In the US, for example, Ireland (2009) and Lucas (2000) examined whether the semi-log or log-log money demand function was the better specification assuming that the income elasticity of M1 is one. More recently, Benati et al. (2017) explore the long-run demand for M1 using a dataset of 32 countries since 1851, including Japan. Our results are partly consistent with Jobst and Stix (2017), who find stable cash demand in economies with no record of financial crisis and an increase in cash demand for economies experiencing a financial crisis in 2008. Note that there were very few financial institution failures in 2008 in Japan; therefore, we should date the beginning of the Japanese financial crisis as earlier than 2008.

We can use our estimates of log-log equation (2) to infer that cash demand would decrease if the BOJ successfully achieved its inflation target of 2% and gradually increased short-term interest rates, because of the stability of our estimated log-log cash demand functions. Note that the log-log cash demand functions fit the pre-1995 data closely, with a cash–GDP ratio of about 8% and positive nominal interest rates, which represent normal economic conditions in Japan. One might wonder if the log-log cash demand functions are stable after the introduction of negative interest rate policy in 2016. However, Saito (2017) showed that the cash–GDP ratio from 1930 to 1955 was stable at around 10% except for around World War II; therefore, an 8% cash–GDP ratio may be a reasonable prediction of future values of the ratio.

Note that in 2016, Japan's Prime Minister, Shinzo Abe, announced a plan to increase Japanese GDP to 600 trillion yen by 2020. If his plan succeeds and if the BOJ helps the Japanese economy escape its current liquidity trap, then it is more likely that the demand for cash could fall to 8% of nominal GDP. In this case, there would be 48 trillion yen (= 600 trillion yen of GDP × 8%) of cash in circulation in Japan, which is about 50% of the average cash in circulation in April 2018 of about 99 trillion yen. An additional concern is the extent to which some new form of payment instrument could reduce the demand for cash more than these estimates predict. It is for this reason we examine the substitution of cash and noncash payment methods in Section 3.

3. Demand for Cash by Households: Evidence from the Survey of household finances

In this section, we analyze cross-sectional data from the Survey of Household Finances (SHF) compiled by the Central Council for Financial Services Information (CCFSI). Using the SHF family household data from 2007 to 2014, Fujiki and Tanaka (2018a) presented three results. First, credit card users generally have higher disposable income, more financial assets, better financial knowledge, younger household heads, female household heads, higher educational attainment, and are not self-employed compared with cash only users. Second, holding other household characteristics constant, credit card users tend to have smaller cash holdings than cash only users for day-to-day transaction values of more than 1,000 yen. Third, credit card users tend to have larger cash holdings than cash only users for day-to-day transaction values of less than 1,000 yen. Fujiki (2019) employed identical statistical methods to those of Fujiki and Tanaka (2018a) for SHF family household data from 2007 to 2017 and confirmed the robustness of their first and second findings and resolved the third puzzling result as below.

3.1. Descriptive analysis

The SHF asks respondents to identify their two most frequently used payment methods for day-to-day transaction values of less than or equal to 1,000 yen (hereafter ≤1k), more than 1,000 yen and less than or equal to 5,000 yen (1k–5k) , more than 5,000 yen and less than or equal to 10,000 yen (5k–10k), more than 10,000 yen and less than or equal to 50,000 yen (10k–50k), and more than 50,000 yen (>50k) from four different payment methods: cash, credit cards, electronic money (including debit card), and other payment methods. We construct an aggregate dummy variable for the five payment methods: cash (respondents chose cash exclusively), card (credit card exclusively, cash and credit card, or credit card and other), emoney (electronic money exclusively, cash and electronic money, or electronic money and other), other (other exclusively or cash and other), and card and emoney (credit card and electronic money). Among the possible payment methods, electronic money is typically a prepaid card using Sony's FeliCa contactless IC card technology used for low value transactions at convenience stores, train and subway stations, and supermarkets. JCB (2018) shows that Japanese credit card holders mostly use their credit cards for payments for online shopping, groceries, and utility bills. Of these, 90% of Japanese credit card holders choose to pay with a one-time payment (within 55 days) free from interest rate charges, rather than through revolving payments.

The top panel of *Table 5* details the proportion of observations for the aggregate payment method choice for day-to-day transactions and the number of observations.

There are three major payment choices of survey respondents shown in the shaded area: cash only and card for all ranges of transaction values, and electronic money for transaction values of 1k–5k and ≤1k. In the following analysis, we concentrate on these major choices. The use of cash for low value transactions and the use of noncash payment methods for higher value transactions are also evident in many other economies (see Esselink and Hernández (2017) for the Eurozone, Greene et al. (2017) for the US, and Henry et al. (2018) for Canada). The second panel of *Table 5* details the mean cash holdings by choice of aggregate payment method.

Proportion of observations and mean cash holdings for aggregate payment method choices for day-to-day transactions and regular payments

Table 5

Choice of day-to-day payment method 2007–2017

	>50k	10k – 50k	5k – 10k	1k – 5k	≤1k
cash only	0,376	0,466	0,668	0,759	0,863
card	0,575	0,502	0,291	0,172	0,047
emoney	0,008	0,010	0,027	0,056	0,083
other	0,037	0,015	0,006	0,004	0,004
card and emoney	0,005	0,006	0,008	0,009	0,003
Number of observations	36.773	37.089	36.826	36.844	36.466

Mean cash holdings by choice of day-to-day payment method 2007–2017

	>50k	10k – 50k	5k – 10k	1k – 5k	≤1k
cash only	15,63	15,24	14,24	14,10	14,01
card	13,09	12,94	12,98	13,58	15,24
emoney	20,97	20,27	15,15	12,00	11,84
other	12,17	10,54	16,48	20,49	18,35
card and emoney	10,76	13,00	11,62	13,23	13,90

Note: In units of 10,000 yen.

Choice of regular and day-to-day payment method 2007–2017						
Regular	**Day-to-day**	**>50k**	**10k – 50k**	**5k – 10k**	**1k – 5k**	**≤1k**
NCC	cash only	0,505	0,602	0,809	0,858	0,922
	card	0,495	0,398	0,191	0,099	0,025
	emoney				0,044	0,053
Number of observations		25.845	26.700	26.443	27.226	27.024
Regular	**Day-to-day**	**>50k**	**10k – 50k**	**5k – 10k**	**1k – 5k**	**≤1k**
CC	cash only	0,069	0,115	0,345	0,495	0,711
	card	0,931	0,885	0,655	0,413	0,119
	emoney				0,092	0,171
Number of observations		8.724	8.813	8.449	8.670	8.810

Mean cash holdings by choice of regular and day-to-day payment method 2007–2017						
Regular	**Day-to-day**	**>50k**	**10k – 50k**	**5k – 10k**	**1k – 5k**	**≤1k**
NCC	cash only	15,74	15,35	14,46	14,39	14,26
	card	13,20	12,96	12,98	14,08	18,28
	emoney				11,81	11,78
CC	cash only	13,31	13,86	12,59	12,53	12,95
	card	12,88	12,84	13,00	13,27	13,37
	emoney				11,26	11,34

Note: In units of 10,000 yen.
Source: Fujiki (2019, Tables 1 and 3).

Respondents choosing card (hereafter card users) tend to have smaller cash holdings compared with respondents choosing cash only (hereafter cash only users) for transaction values of more than 1k, and higher cash holdings for transaction values of ≤1k, which is the third result of Fujiki and Tanaka (2018a).

Fujiki (2019) resolved the puzzling third result of Fujiki and Tanaka (2018a) in two ways. First, in the second panel of *Table 5*, respondents choosing electronic money (hereafter emoney users) for day-to-day transactions tend to have smaller cash holdings compared with cash only users for transaction values of 1k–5k and ≤1k. Second, using data on regular payments, the average cash holdings of card users choosing credit cards for regular payments are less than those of cash only users not choosing credit cards for all ranges of transaction values, as explained below.

The SHF asks respondents about their two major payment methods for regular payments from among the five options of cash, credit cards, electronic money, automatic withdrawals, and other. Cash payments usually mean that customers receive barcode-based utility bills via mail, and then they visit a convenience store to pay these bills by withdrawing cash from a convenience store automated teller machine (ATM) on a 24/7/365 basis. Automatic withdrawal (a direct debit or kouza furikae in Japanese) refers to an arrangement whereby a depositor will grant permission to a seller to take payments from the depositor’s bank account automatically and regularly, for example, monthly. Many Japanese banks have offered automatic withdrawal services for the payment of bills for utilities, public television services, credit cards, internet providers, newspapers, and insurance premiums since the early 1970s. As 90% of Japanese credit card holders choose to pay using a one-time payment, from the consumer perspective, credit cards are a close substitute for automatic withdrawals using regular payments, with the additional advantage of the accumulation of points with the use of credit card payments.

The SHF shows that 99% of respondents choose one of the following six choices: automatic withdrawal only (47%), cash and automatic withdrawal (21%), cash only (8%), credit card and automatic withdrawal (14%), credit card only (6%), and credit card and cash (3%). We refer to the sum of the first three choices not involving credit cards as ‘NCC’ (No Credit Card users for regular payments), and the sum of the three remaining choices involving credit cards as ‘CC’ (Credit Card users for regular payments). We call the sum of all remaining choices (1%) 'All the rest'. NCC and CC represent the payment behavior of, respectively, 76% and 23% of the sample households (excluding the 1% in 'All the rest').

The third panel of *Table 5* details the choice of day-to-day payment methods conditional on the choice of either NCC or CC. This shows that CC households chose card and emoney more frequently than those choosing NCC. The fourth panel of *Table 5* indicates that card users choosing CC (hereafter Card & CC) have smaller cash holdings than cash only users choosing NCC (hereafter Cash & NCC) for all transaction values, which resolves the third puzzling result by Fujiki and Tanaka (2018a). Behind this resolution lie the reasonable exclusions of card users choosing NCC and cash only users choosing CC two groups from the analysis as below. First, card users choosing NCC exhibit a special preference because they are willing to forego the opportunity to accumulate points through credit card usage by making bill payments. *Table 5* indicates that they have relatively large cash holdings compared with other users for transaction values of ≤1k (the shaded values). Second, we exclude cash only users choosing CC because Fujiki and Tanaka (2018a) compared people using cash only with those using noncash payment methods.

3.2. Regression analysis

Fujiki (2019) verified the results of his descriptive analysis using regression analysis, first estimating logit and multinomial logit models that regress the indicator variable of the payment method (card and cash, with emoney for 1k–5k and ≤1k, and the combination of card, cash, emoney as well as CC and NCC) conditional on various demographic variables related to the choice of payment method. Then, he estimated conditional cash demand taking into consideration the endogenous payment choice. The qualitative results for the logit and multinomial logit models and those for conditional cash demand model reported are similar to Fujiki and Tanaka (2018a). Fujiki (2019) also estimated the average treatment effects (ATEs) and the ATEs on the treated (ATETs) using the inverse probability weighting (IPW) on the cash holdings according to the choice of credit card and electronic money against the choice of cash, and according to the choice of *Card & CC* against the choice of *Cash & NCC*.

The row labeled 'Result 1' in *Table 6* replicates Fujiki and Tanaka (2018a) using the data from 2007–2014. It reports the differences in the unconditional average of cash holdings in the fourth column. The fifth column details the means of the predicted cash holdings using the estimates of conditional cash demand, with the t-tests indicating whether the mean cash holdings for cash users, emoney users, and cash only users significantly differ. As shown, credit card users on average tend to have smaller cash holdings than cash only users for day-to-day transaction values of more than 1k. Similarly, the sixth and seventh columns show that card users tend to have larger cash holdings than cash only users for day-to-day transaction values of ≤1k, while the ATEs and ATETs are not statistically significantly different from zero. These results are very similar to those in Fujiki and Tanaka (2018a) using data from 2007–2014 and reported in the row labeled 'Result 2'. While replicating their results, we found some coding errors in the computer program. Nevertheless, there is little change in the results, even after correcting these errors, as reported in the row labeled 'Result 3'.

Fujiki (2019) resolves the third puzzling result of Fujiki and Tanaka (2018a) as follows.First, the row labeled 'Result 4' indicates that electronic money users tend to have smaller cash holdings than cash only users for day-to-day transaction values of 1k–5k and for ≤1k irrespective of the choice of estimation method. Second, the row labeled 'Result 5' reports that the differences in the mean predicted cash holdings of those choosing *Card & CC* and those choosing *Cash & NCC* are statistically significantly negative, even for transaction values of ≤1k, as shown in the fifth column. While the ATETs support this finding, the ATEs are not statistically significant for transaction values of ≤1k. However, the results from the ATETs are sufficient to show that those currently choosing *Card & CC* have smaller cash holdings than those choosing *Cash & NCC*.

Differences in mean cash holdings

Table 6

Results	Sample period and data	Transaction values	Unconditional mean	Predicted value by a conditional cash demand function	ATE (IPW)	ATET (IPW)
Result 1	2007-2017 card vs cash only	>50k	-2,541	-2,553***	-3.141***	-3.090***
		10k - 50k	-2,306	-2,306***	-3.316***	-3.116***
		5k - 10k	-1,265	-1,242***	-2.829***	-2.332***
		1k - 5k	-0,518	-0,455***	-2.438***	-1.896***
		≤1k	1,230	1,266***	-0,516	-0.549
Result 2	2007-2014 card vs cash only Fujiki and Tanaka (2018a) Tables 7 and 8	>50k	-3,018	-3,018***	-3.524***	-3.624***
		10k - 50k	-2,489	-2,489***	-3.315***	-3.312***
		5k - 10k	-1,370	-1,370***	-2.596***	-2.028***
		1k - 5k	-0,386	-0,386***	-2.031***	-1.221*
		≤1k	1,063	1,062***	-0.843	-0,019
Result 3	2007-2014 card vs cash only Correction	>50k	-3,020	-3,020***	-3.506***	-3.627***
		10k - 50k	-2,490	-2,490***	-3.256***	-3.222***
		5k - 10k	-1,374	-1,374***	-2.565***	-1.920***
		1k - 5k	-0,396	-0,396***	-2.063***	-1.137*
		≤1k	1,065	1,065***	-1,108	-0,202
Result 4	2007-2017 emoney vs cash only	1k - 5k	-2,103	-2,061***	-1.621*	-1.983***
		≤1k	-2,169	-2,133***	-2.612***	-2.675***
Result 5	2007-2017 Card & CC and Cash & NCC	>50k	-2,858	-2,870***	-3.448***	-3.268**
		10k - 50k	-2,507	-2,495***	-3.716***	-3.248***
		5k - 10k	-1,463	-1,388***	-2.911***	-2.785***
		1k - 5k	-1,124	-1,037***	-2.822***	-2.837***
		≤1k	-0,890	-0,851***	-1,914	-2.645**

Notes: In units of 10,000 yen. IPW stands for inverse probability weighting.
* p<0.10, ** p<0.05, *** p<0.01
Source: Fujiki (2019, Table 6).

The results in *Table 6* suggest that credit card users tend to have smaller cash holdings than cash only users by about 30,000 yen for transaction values of >50k. A back-of-the-envelope calculation by Fujiki (2019) suggests that the maximum impact on aggregate cash demand if all Japanese cash users became credit card users would be very small. First, according to forecasts by the National Institute of Population and Social Security Research, there were 34,904,000 non-single-person Japanese households in 2017. Second, the top panel of *Table 5* shows that about 40% of family households are cash only users for transaction values of >50k. Hence, if all Japanese cash only user households with day-to-day transaction values of >50k reduced their cash holdings by 30,000 yen as they became credit card user households, the resulting decrease in overall cash demand would be 34,904,000 households × 40% × 30,000 yen/household = 419 billion yen. Notably, this represents just 0.4% of the 105 trillion yen in cash in circulation in Japan in 2017.

4. Conclusion

Why has the ratio of currency in circulation to nominal GDP in Japan increased despite the advances in noncash means of payments? We argue that the cash demand for hoarding was so strong that it outweighed the negative effect of the substitution to noncash means of payment on the cash demand for day-to-day payments by analyzing two types of demand for cash separately: for hoarding (Fujiki and Tomura (2017) and Section 2 of this paper), and for daily one-off payments (Fujiki (2019)). We obtained the following results. First, using aggregate data on cash in circulation in Japan, we find that cash hoarding could represent as much as 42% of the total cash in circulation. If we assume a semi-log cash demand function, there is a significant structural change in the parameters of cash demand in the late 1990s or early 2000s. If we assume a log-log cash demand function, there is no structural change in cash demand. The long-run income elasticity of demand for cash is one, but the implied interest rate semi-elasticity of cash demand varies substantially especially during the period of the first round of quantitative easing. An accelerating growth rate of the demand for cash that exceeds the nominal economic growth rate after the mid 1990s could be explained by a combination of a stable unitary income elasticity of cash demand and very large implied interest rate semi-elasticity of cash demand. Second, the Japanese household survey data suggests that emoney users tend to have smaller cash holdings compared with cash only users for transaction values of 1k–5k and ≤1k, and the average cash holdings of card users choosing credit cards for regular payments are less than for cash only users not choosing credit cards for all ranges of transaction values, which resolves the third puzzling result of Fujiki and Tanaka (2018a). The possible decreases in cash demand from the substitution of cash for noncash payment methods under current technology for day-to-day transactions implied from those results would not be very large.

Based on this evidence, we argue that the BOJ should be more mindful about any reduction in cash hoarding, for example, because of an increase in the policy interest rate in the future, than about the substitution of cash for credit cards for daily transactions or regular payments, when forecasting the trends in cash usage in Japan. An important reservation is that our evidence concerning the substitution of cash for noncash payment methods reflects the technology available in the period 2007–2017.

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Erin B. Taylor, Gawain Lynch
From cash to choice: Uptake of digital financial services in the Netherlands

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Abstract

Historically consumers around the world viewed cash as providing greater reliability, security, and privacy compared with digital products (Ho & Ng 1994; Khan et al 2015). For example, cash was viewed as easier to account for and budget, whereas using cards made it easier to overspend (Feinberg 1986). Today, however, preferences and practices regarding cash are being challenged by the proliferation of digital financial services, ranging from established tools such as cards and online payments, to new "fintech" services such as non-bank card readers, transfer apps, "pay me" services and alternative currencies. As a result, attitudes to cash and digital financial tools are shifting markedly (Arango-Arango 2018; Kamleitner & Erki 2013; Penz & Sinkovics 2013; Taylor forthcoming).

In this paper we present the results of our "portable kit" study of payments in the Netherlands (Taylor 2017a; Taylor & Lynch 2017). Cash is used less in the Netherlands than in any other country in the Eurozone (Esselink & Hernández 2017; Jonk-

er et al 2017; Jonker et al 2012; van der Cruijsen et al 2007). We found that attitudes to payments tools have effectively reversed in the past decade or so (Taylor 2018a, 2018b). Most respondents used digital financial tools to both make transactions and to create household budgets. This has resulted in a significant transformation in both attitudes and practices towards digital and analogue money. We explore this shift and its implications for both consumers and the growing market for new financial products and services.

Introduction

Gone are the days when consumers did their banking in cash in their local village or "high street": instead, products and providers can (within regulatory and practical limits) reach consumers anywhere around the globe. A person can pay their credit card debt while riding in a train, do their grocery shopping online as they sit in a café, bet on a football match while perched on a public toilet, or buy illicit drugs using Bitcoins as they head out for the night.

Along with people and products, information is also far more mobile. People can find extensive product information online, and they can share their personal information far more easily. Business models are also changing, because the "unbundling" of banking, new technologies, and regulatory reform make it is easier for start-ups with highly specialised products to enter the market.

These changes make both the supply side and demand side of the market more complex, presenting challenges for understanding changing consumer behaviour and building robust business models (CGI 2014, Muller et al. 2011, Xiao 2008). Quantitative data make it clear which countries and demographics still prefer cash, what they prefer to use it for, and how and when they use it. Yet quantitative methods generally highlight normative trends, and do not shed significant insight into people's changing attitudes and values. It is difficult to predict the future: we cannot readily foresee how consumers will respond to increased choice in payments tools, which service providers will come to dominate the market, or how society will be affected as cash disappears.

In this paper we report on the results from our study of payments behaviours in the Netherlands. Using an innovative interview method called the ‘portable kit study’, we asked people to show us the tools people use while they are away from home and talk us through their decision-making processes. Our intent was not to understand normative trends; in fact, it was the opposite. We wanted to uncover unusual stories, use cases, and values, in an attempt to spot potential future trends in behaviour and money culture.

We did not set out to study cash specifically–in fact, we assumed we would probably not learn anything significant about it, given that cash usage in the Netherlands is low. Yet cash did indeed present some interesting results in our research. The most surprising of these was the way in which people accounted for their money using cash or card. We do not claim that our sample is representative, or in any way predictive. Rather, we argue that interrogating the long tails of human behaviour can help us to question our former assumptions about psychological and cultural relationships with different forms of money, and diverse ways of accounting for it. Qualitative methods, such as the portable kit study detailed in this paper, are especially useful for investigating long tails because they can be adapted to explore topics not well understood by researchers, and can incorporate techniques to uncover insights into human behaviour that people themselves find difficult to articulate or understand.

Methodology

We used the “portable kit method” of interviewing people about the objects they carry with them while away from home. In this method, interviewees are asked to bring along all the things they usually carry with them on a daily basis. The interviews were semi-structured: while the researchers followed the same general process for each interview, they also followed particular topics based on what their interviewees told them. People can understandably be reluctant to talk about money, but we explained up-front that we were not interested in personal information, such as people's salaries, debt levels, or spending patterns.

Interviews begin with background questions about the interviewee, their life and their work. Then they are asked to take all of the objects they carry with them out of their bags, pockets, and wallets, and display them on a flat surface. This included objects related to consumer finance (currency, cards, receipts) and other items (identity documents, photographs, pens, notebooks, etc.).

Then the interviewees were asked to divide the objects into two piles: one of objects that they must carry with them every day, and a second pile of objects that could be left at home. The interviewees were asked to explain why some items were more important than others. This step was crucial in identifying what people felt they needed to navigate their everyday lives. As the interviews progressed, the interviewers formulated questions that would tell them how different objects were involved in personal and household finances.

First, we asked about their non-financial objects so that we could get a sense of the person. Interviewees were invited to discuss the objects generally. The interviewers often began by asking about the bag or wallet itself: where it had been purchased, why they chose that particular item, and whether they own other bags that they switch between depending upon their plans for the day. The benefit of this initial step was that it gave participants a chance to relax and provided an opportunity to build rapport.

Second, we asked people to talk to us about all their possessions that relate to financial transactions: cash, debit cards, credit cards, store cards, receipts, and tokens. We then asked people to show us what apps and websites they use on their mobile phones to do financial transactions. Finally, we asked questions about how people feel about the role financial services play in the lives, and are likely to play in the future.

The portable kit interviews were recorded using an audio device, a video camera, and a still camera. Interviews ranged from forty-five minutes in the case of one participant who had already been interviewed multiple times and did not carry many items, to three hours for people with many items or an unusually extensive collection of phones and SIM cards. This method has several advantages in consumer finance research (Taylor and Lynch 2016):

1. People are usually not accustomed to talking in detail about their use of financial tools and services. Asking people about the financial tools they carry can help the interviewee to open up about their behaviours. They can also help interviewees to stay on topic by providing a point of focus. For example, interviewees may find it easier to show the interviewer the contents of their wallet than to recall all the money-related items they carry.
2. Consumer finance research often requires interviewees to recall details about their financial transactions and the products they use, but much of this information is either never memorized or is difficult to recall. Props such as wallets, credit cards and bank statements help us to recall information that is recorded on the props themselves or that is in our memories. For example, asking an interviewee who regularly sends money overseas to show you their receipts will confirm the dates on which they made transactions.
3. The method also provides the researcher with an opportunity to ask about objects that the interviewee has overlooked. Whereas the interviewee may only point out items they associate with financial management, such as cash and credit cards, an interviewer may also wish to know about other kinds of money, such as store cards, or secondary items such as identification documents and receipts.
4. The meaning of interview questions is not always clear to interviewees, and using visual / textual aids can help the interviewee understand exactly what is

being asked. For example, when interviewing a person about their use of spreadsheets for budgeting, being able to point directly to a particular item in the spreadsheet and ask a question about it can save time and confusion. This technique may be especially useful when interviewing children as it can help them to understand what the interviewer is asking them.

5. Props allow for the specific features of an object to be discussed. For example, an interviewer might ask a customer to demonstrate how they use their mobile phone to send money and comment on the steps involved as they are carried out. This gives the interviewee a chance to explain what they do and don't like about the functionality and aesthetics of the object, and to identify any stumbling blocks.

The portable kit study enabled the researchers to understand how people living in the Netherlands used financial services in their everyday lives. The objects people carried with them reflected both this formal financial environment and alerted the researchers to a range of other, less visible financial practices.

Cash and choice

Cash usage in the Netherlands has dropped steadily in recent years, with the preference for cash dropping from 32% in 2013 to 28% in 2016 (Jonker 2018). Dutch people do not often use credit cards; if they have one they often keep it at home in a drawer, using it mainly for online purchases. Instead, Dutch people's preferred payment method is the debit card. This ubiquitous payments tool is accepted in virtually all retail outlets, including pop-up market stalls. Mobile wallets are available, but use is still low. For online payments within the Netherlands (and occasionally abroad), the Dutch e-commerce payments system iDEAL is standard. There are also several apps available to assist people in splitting costs, such as for restaurant bills. Tikki, an app developed by several Dutch banks, provides an easy way for people to request payment from other individuals.

The Dutch debit card is so widely accepted that, to its users, it appears to form the basis of a seamless payments system. However, people (usually foreigners) who do not have a Dutch debit card quickly encounter friction making payments. Many retail outlets, including restaurants and some parking meters, do not accept credit cards at all; some accept only credit cards from certain jurisdictions. An increasing number of shops (usually supermarkets and convenience stores) do not accept cash. The Dutch debit card therefore acts like a financial 'passport': without it, consumers can find themselves undertaking complicated procedures to make payments–or leaving their groceries unpurchased at the point of sale. Thus while technically consumers' choice of payments tools is increasing, we see little change in payments behaviour, with the debit card remaining prominent.

In our study we encountered a wide range of items relating to finances in people's portable kits (see *Table 1*). These included different currencies, credit cards,

Finance-related items in interviewees' portable kits Table 1

More common items	Less common items
Cash	Credit cards
Debit cards	eReaders
Transport cards	Gift certificates
Store cards	Annual museum entry card
Health insurance card	Tag for bicycle parking
Receipts	Non-bank mobile apps, e.g., other financial services or pay for parking
Discount vouchers	
Mobile banking apps	Shopping directly on mobile via an app or website (e.g. Picnic)
Using mobile to scan QR codes when shopping on the computer	A Chinese coin for good luck

receipts, discount vouchers, and store cards. They also carried items such as house keys, photographs of family members, pens, paper, and mobile phones. However, the central role of the debit card was evident in the results of the Portable Kit Study. Every wallet we encountered held one.

Indeed, many people will leave their wallet at home, and go out carrying only their mobile phone with their debit card and transport card stored in the phone cover. Some people used bank apps such as ABN Amro's Grip app, external tools like WhatsApp's "pay me" reminder, or features like QR codes that allowed swift completion of payment.

Most interviewees had very simple financial set-ups: some had been with the same bank their entire lives, and many had switched banks only once or twice. Many sourced all their financial products from the one bank, including insurance. Most could think of no good reason to change financial service providers, since they seem to all offer the same range of services. Two exceptions were:

1. People who switched providers due to a change at the bank: one woman changed providers to avoid having to use a token to log into her account (she preferred a password-based login).
2. People who changed providers for ethical reasons. One interviewee switched to a small alternative bank called ASN Bank because he was not happy when his previous bank privatised.

Some interviewees said they would like to switch banks, but they could not find the time. Our interviewees were far more likely to adopt new services and features than switch providers completely. Thus, for our interviewees, 'choice' was more about access to products with sufficient functionality and ease of use than preference for service providers.

Carrying cash: Practical and psychological motivations

We asked our participants, "How much money do you carry with you on a daily basis?" On the whole they carried very little cash, with amounts ranging from EUR 0-40. They tended to withdraw cash from an ATM once every week or two. Cases in which participants carried cash because it was the only way to pay for a service included some market stalls, sporting activities, festivals, giving money to people on the street, and tattoo shops. For the most part, they saw cash as being largely unnecessary, since virtually all commercial outlets in the Netherlands accept debit cards. Most carried cash for a sense of security rather than for practical means. One respondent uses cash largely because some of her clients pay her in cash. Moreover, it can be difficult to find ATMs, and this further encourages the use of debit cards.

Participant 2, a graphic designer in her thirties, reported that she still carries cash, but does not often use it. She told us that she keeps at least EUR 10 in her wallet because she knows there are places where you can't use a debit card. However, at the time of interview she had been carrying EUR 35 in her wallet for at least three months, and expects that it will stay there for a few months more. She told us, "If I can use the bank card, I will."

Sometimes people would also pay for small items with cash, even though they knew it is perfectly acceptable to pay with debit card. This is because in the past, shopkeepers did not tend to like it when people paid with debit card for small purchases, and so paying with cash is still a force of habit. One participant (P4), a woman in her thirties who works as a tattoo artist, told us that she still often pays for small items with cash, such as a cup of coffee, even if she knows card is acceptable (and even preferred). She is starting to pay for small things with debit card, but it feels strange to her. We asked her if she remembered the last time she absolutely had to pay with cash because they didn't accept debit card. She responded that this happened to her recently, but she could not remember what she was trying to purchase. She could not recall any instances in which not having cash on hand presented a major issue.

At times people's tendency to carry cash is the result of their uncertainty about what can be paid by debit card and what cannot. The same participant (P4) told us that she would usually carry around EUR 50 in her wallet. She told us that she always wants to have cash on hand because "you never know what will happen". For example, two months ago, her partner was sick and needed a taxi to go to the doctor. She gave him cash to pay for the ride because she did not know if taxis accepted debit cards as she had never paid for one using that method.

The ubiquity of the debit card is evident in people's attitudes to both the functionality of cash and the structure of the financial system. One of our interviewees (P3), a retired man in his late 60s, said that he would usually carry around EUR 40 in cash. He estimated that at least 70% of his transactions are with a debit card, and that this has been the case 'for a long time' in the Netherlands: it is no longer possible to not have a bank account. He felt that paying with a card is easier than with cash because there is no need to fish around for the right money. He does not like Euro coins; he told us that they are "slecht geld" (bad money) because you cannot easily differentiate between them. Thus his attitude to cash and card is somewhat ambiguous: on the one hand he is not entirely happy that it is no longer possible to choose not to have a bank account; on the other hand, he views the debit card as being more user-friendly.

Accounting for spending: Cash as 'free money'

In their survey of card and cash usage in the Netherlands, Jonker et al. found that:

> "Cash is still most preferred because of budget reasons; seeing what is still left in the wallet (and what is not) helps people keeping track of their spending (82%). Other frequently mentioned reasons for preferring cash are that it is a habit (68%) and that the payment feels 'more real' with cash than with debit card." (2018: 38)

Such a finding is not surprising: research showing that people overspend with both debit and credit cards, and budget better with cash, has been demonstrated for decades (Feinberg 1986; Moore and Taylor 2011; Runnemark et al 2015). The theory is that cash is more tangible and visible, and this makes it easier for people to track their spending. In contrast, payments made with cards tend to be more invisible; people may swipe a card without paying too much attention to the price until the bill arrives in the mail a few weeks later. Moreover, some anthropological literature demonstrates how cash is preferred for accounting purposes, since it can easily and visibly be earmarked and stored for separate or special purposes (see, for example, Maurer 2006; Mesfin 2014; Zelizer 1994). This was indeed the case for some of our interviewees. Participant 2 told us:

> “You can see what you’re paying and what you get back. I tend to be more aware of what I buy and how much it costs when I pay with cash than if I just pull out my card. Sometimes I don’t even look at what the cashier types in, I just say, okay, plllp. And later I find a receipt and go, oh fuck, it was the wrong number, or she forgot something, or… I’m not very attentive in that sense.”

However, not all of our participants viewed cards as encouraging spending and reducing their ability to track what they had purchased. Participant 4 reported that she did not feel she spent more with card or cash; both were equal. However, Participant 1, a female in her early forties, was unusual in that she felt she made more spontaneous and indulgent purchases when she used cash. She told us that she sees cash as not being “real money”. When she used to work in bars, ‘cash was everything’ and she was very aware of how she managed it. She would try to put her pay in her bank account as quickly as possible so that she would not spend it, but she held onto tips in cash as they were ‘for playtime’. When she got a ‘real job’ and her salary was paid into her bank account directly, she began keeping around EUR 20-30 in her wallet as a ‘slush fund’ for things like coffee or other small purchases. She tries not to carry much cash around precisely because she will spend it:

> *Participant 1:* If I have cash in my wallet, it's like it's not real money. It just goes.
> *Interviewer:* Right, so that's a motivating factor for you not carrying cash?
> *Participant 1:* Yep. If I've got cash in my wallet, I'll spend it.
> *Interviewer*: What is it about the cash that makes you spend it?
> *Participant 1:* Dunno, it's like it's not real money. It's–it sounds weird. If money is in my account, and I'm paying through the card, I'm like mentally aware of what is going out and I've got an app on my phone so I can check my bank balance and so on and so forth, and I can pay via my phone, and it's fine. But when there's cash, it's basically–if it's in your wallet, it's already spent … So, it's been, it's spent, I've already taken that into consideration in my monthly life, and then all of a sudden some money's come back to me and I'm like, ooh! Off to the art shop I go.

In other words, her accounting takes place digitally. If it is not in her bank account, it doesn't need to be accounted for. She continued:

> "So long as I've got enough money in my account to pay the bills and to feed us and so on, there's like this weird kind of triangle and there's this floating area of a no man's land where money's gone out and it's come back, but it's not come back yet, and therefore it's mentally sort of allocated elsewhere, so I don't think about it. So the money in my account, the number in my account, that's the important number."

While this participant was unusual in that she had long viewed cash as unaccounted for, we found a general preference among our interviewees for accounting digitally rather than in cash. With the advent of online banking and easy to use banking apps, most of our interviewees reported that they found it easier to track their spending digitally. They would often log into their banking apps on their phones many times each day to check purchases made and the account balance. This had the effect of reversing their psychological relationship to cash.

This habit of accounting digitally also affected whether interviewees stored cash at home. While some kept odd coins in jars and in their cars, most had shifted from storing notes at home. Participant 4 told us that they used to keep cash at home to save money: if it was not in her account, she could not spend it. Now she saves her money in one account because she found it inconvenient to not be able to make purchases spontaneously. Because she has shifted from accounting with cash to accounting digitally, she is less concerned about the risk of making spontaneous purchases, since she can easily log into her banking app to check her recent expenditures and overall financial position.

Using digital and mobile banking

As our interviewees shift from cash to digital accounting, they encounter obstacles and develop new habits. One important point that several interviewees noted is that digitally is only effective if they have limited cards or can aggregate their transaction details in one place. None of our interviewees used a third party aggregator or budget management tool (such as Mint[1]). Rather, they deliberately limited the number of accounts they held. Several only have one account, and few have more than two. Others would have a personal account and a savings account, a personal account and a business account, or a personal account and a joint account with their partner.

There was substantial difference in how people used digital accounting tools, ranging from only logging into their bank account at home, to completing all kinds of transactions while in public. Participant 3, our retired teacher, did not use mobile banking. Instead, he would log into his bank account on his computer at home every day to check how much money he has spent. He "does not trust" the mobile phone for transactions, but was not able to specify exactly why. He does not check his balance at an ATM either. While he is somewhat unusual in preferring computer over mobile to manage his finances, his case is indicative of the ubiquity of the

1 See their website, https://www.mint.com/

drop in cash use in the Netherlands. Even people who are used to handling cash as their primary payment mechanism have moved away from it in favour of more functional digital payments.

Participant 4 was undergoing a slow transition to mobile transactions. She had already used online banking for years, but only installed the app on her phone two months prior to the interview. She described herself as a "very old-fashioned" person who "takes a long time to get used to things". She quickly discovered that she likes the app because "I'm a control freak, I have to know what's going on and with the phone you can see that.'

Participant 1 is a step ahead of Participant 4 in how she uses mobile banking. Although she has shifted mentality from cash to digital she is still getting used to using the Rabobank app. She recently began checking her bank balance on her phone, and does not know why she didn't want to do it before. Now she is using the app she is finding it to be extremely convenient. She uses it to check her balance, transfer money between her own accounts, pay friends money owed, and pay bills. She has become so used to using her phone for her financial transactions that she will use it even at home, rather than go to her computer. She finds it more convenient to continue to sit on the couch. The one exception is online purchases: she will browse online stores using her phone, but will go to the computer to complete transactions as she finds the interface easier to read, and thus safer to use. This use of the mobile at home is interesting in how it allows users to be less mobile rather than more (they can stay on the couch!). Yet it is the very mobility of the mobile phone that permits users to stay immobile.

The mobile phone has made a significant impact in other ways. The ability to do transactions on the phone increases convenience, and–most importantly–reduces stress by allowing people to make transactions instantly and while on the go. Participant 2 described to us how she was saved by the embarrassment at the supermarket checkout when her payment was rejected, as she was able to instantly transfer money from her business account to her payment account. The alternative would have been to either abandon her groceries at the checkout, or alternatively ask the cashier to store them behind the counter while she looked for an ATM to either transfer the money or resolve cash.

While mobile banking can raise issues of its own (such as when cards and apps do not properly function), it provides a greater number of ways of transacting and grants users alternative pathways to complete transactions. The ability of mobile devices to reduce transaction costs, reduce the stress of financial transactions, and smoothen consumption should not be underestimated. In fact, the utility of these features for users is little understood; further studies would be useful to shed light on the ways in which digital and mobile financial services benefit consumers or present stumbling blocks.

Fears about the future of finance

In the fintech world, there is a great deal of excitement about new financial services. Fintech companies and commentators generally paint a picture of a world full of consumer choice and better options. Regulators echo this enthusiasm when they point out that new regulations, such as PSD2 and GDPR, will help consumers have more choices and better control over their data.

However, many of our interviewees were more worried than excited about the future of finance. They were concerned about digital finance raising security issues, that cash would disappear and all their finances would be tracked, they would be forced to use particular services they didn’t like, and that their data would no longer belong to them. As one interviewee put it:

> “The future terrifies (...) me. It’s–knowing even slightly a little bit of what I know now, personal information, personal data, and how it’s getting used, and people

don't know it's getting used because nobody thinks about it. We just blindly accept [browser] cookies because, you know. But what you're actually agreeing to is your data can be used at any point in the future, it's not yours any more. And that–if a website doesn't work without cookies, then you do not want to be on that website."

As Dutch consumers shift their financial habits from cash to digital, fears and questions arise with respect to security. Some participants could explain their fears quite concretely; for others, they constituted a vague feeling of unease (for example, Participant 3, who "does not trust" the mobile phone for transactions).

Not all security fears are concerned with as yet non-existent financial tools; concerns are also still held about cash, with some interviewees expressed fears around handling cash in public. Participant 4 told us that she does not like taking money out of ATMs that are not connected to banks (such as in convenience stores), or ATMs that are located in places she feels are not secure. She takes cash out at a particular ATM of her own bank that is located near her home.

Nonetheless, technological changes do tend to produce the greatest fear responses. In the Netherlands, contactless card payments are in virtually all retail stores and are used extensively. Yet some of our interviewees had not activated the service because they worry that strangers with a scanning device will be able to read their cards and rack up charges (although for amounts over EUR 25 customers must also enter their PIN). Participant 3, for example, told us that he does not use contactless payment, but is afraid that in the future there will be no choice but to use it. He is also concerned that he will no longer be able to use his debit card and that everything would be done by phone. He doesn't see the phone as safe. Computer is safer because you have two firewalls. If you buy in a secure shop, that's one firewall, and then when you go to pay with your bank, that's another firewall.

Why is there such a big difference between what consumers think, and what companies/regulators say? Our data suggest that whereas fintech is touted as given consumers more choice, customers see it as potentially removing control away from consumers. Being forced away from cash, being required to use specific digital tools, and not understanding how these tools work all cause consumers to feel they are losing control. Even if consumers have more products to choose from, if they do not feel they have control over how they use them, then their feeling of having choice is reduced. Thus we must view choice not only in terms of the number of products available to consumers, or in terms of their functionality, but also with respect to whether consumers feel that they have agency over how these digital products and financial ecosystems enter their lives.

Conclusion

The shift from cash to digital financial management is virtually complete in the Netherlands as few payments are made in cash. However, the fact that virtually all residents primarily use digital financial tools does not mean that they are all use them to the same degree, or in the same ways. As our results show, some people use a debit card and internet banking but are wary of mobile banking. Others use mobile banking, but are cautious about trying new features or logging into their accounts in public. Many have discovered that digital financial services yield benefits they did not expect, such as relieving stress or helping them feel they have more control over their finances.

When assessing consumer adoption of financial services we should pay attention not only to how many people have shifted to digital financial services, or even which digital features they are using, but also how they themselves judge the utility of these services in their everyday lives. On the flip side, we also need to pay attention to issues of risk, security and harm. While the suppliers of financial services are enthusiastic about their possibilities for consumers and society, those on the demand side are rather more reserved, and in fact are worried about the future.

There are several groups we should consider when thinking about risk. First, there are the early adopters. They may seem like a strange group to identify as at-risk, since they are technologically savvy and would seem to be one of the groups least at risk. However, they are at the frontline of adoption and are therefore the first to engage with new products and services that may not have been properly tested, assessed, or regulated. Second, there are people who have limited literacy of some kind, such as textual, numerical, financial, or technological. These include groups that are not technologically savvy, such as the elderly; people whose first language is not the national language, and people who have low levels of education. A third group is those who are exposed to risk due to a higher level of socioeconomic marginalization. This includes people who take on debt to cope with poverty, or who purchase financial products from uncertified providers because they cannot afford more expensive products. This is just a small selection of possible at-risk groups, and who is "at risk" will differ from place to place. Given the complexity of digital services and their adoption, we cannot assume that we know who will face the highest level of risk.

How can we stay abreast of the issues that consumers face in an increasingly mobile world of money and finance? The digitisation of consumer finance presents methodological issues for tracking changes in consumer behaviour. New financial products are appearing every day, meaning that data are not up-to-date. Furthermore, diversity in product use is not accurately reflected in statistics, since "traditional" modes of payment such as a credit card are used to purchase further consumer finance products (e.g., buying online insurance, sending money, depositing money in an e-wallet). We therefore need to be prepared to draw upon multiple methods from our research toolboxes. We cannot assume that either qualitative or quantitative methods will give us the answers we need. Data analysis can be a highly effective way to spot big-picture trends and tell us what is happening, while qualitative research can tell us why people are behaving in certain ways, or provide early information about changes in the market. For example, central banks and other financial institutions routinely compensate for "data lag" by conducting qualitative research, especially in times of rapid change (Holmes 2013).

Moreover, research needs to be future-facing. We need to both generate insights into changing consumer behaviour and keep a bird's-eye view on the development of the market overall. This will assist us to build a picture of the risks likely to arise in the near future. Researchers, practitioners, and regulators need to be aware that consumer finance product consumption today is taking place in a complex global market, and design our research and policy accordingly to protect consumers. Solid research will inform us of what kinds of interventions are needed, how regulation and policy might respond, and in what ways we need to accommodate people's existing practices.

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Johana Cabinakova, Frank Horst, Fabio Knümann

The costs of payment methods in the retail sector

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Recent years have seen both academics and the public at large taking a greater interest in the costs associated with means of payment. As part of its statutory mandate, the Bundesbank seeks to hone its understanding of the costs of different payment instruments, thereby contributing to an objective discussion of their advantages and drawbacks. In 2014, the Bundesbank therefore published an overview as well as initial estimates of the costs and benefits of cash and cashless payment instruments. This approach was built on to produce the present study, "The costs of payment methods in the retail sector". With its focus on the retail sector, the study looks at a portion of the costs generated in the economy by the use of payment media.

The German retail sector processes roughly 20 billion transactions per year, of which just over 76% were cash payments in 2018. As a percentage of sales, cash payments still account for just under 50%. Innovations in the field of payments, and the new payment procedures that they are ushering in, are giving consumers an ever increasing variety of payment instruments to choose from. One area in which this is being reflected is the growing number of cashless transactions. Against this backdrop, the question of how much cash and cashless payments cost the retail sector is becoming increasingly important–because whatever means of payment consumers decide to use, they all generate costs. A large part of these costs is borne by retailers.

According to the present study, the total costs of payment procedures to German retailers in the narrower sense amount to €5.7 billion per year. Cash payments account for some three-quarters of all transactions and generate roughly €3.8 billion in costs. Taken together, card-based payment methods (such as girocard, direct debit and credit card) cost around €1.7 billion per year. The costs incurred for payments by invoice, finance purchases and voucher payments add up to about €0.3 billion.

Cash payments cost just under €0.24 per transaction, making them currently the most cost-efficient means of payment for retailers from a transaction perspective. According to the study's findings, girocard payments cost €0.33 per transaction, while SEPA direct debit payments cost €0.34. On account of higher transaction costs, credit card payments work out more expensive than cash or girocard payments from every perspective and generate costs of just under €1 per transaction. In terms of sales, however, card payments and, in particular, girocard payments prove cheaper for the retail sector than cash payments. When interpreting the figures, it should also be borne in mind that the costs presented are based on average values and that different payment structures have to be taken into account. The present survey from 2017 was only able to capture a small number of contactless payments. Broader uptake of this relatively new form of payment could see the costs of card payments, in particular, change. This underlines the fact that the costs associated with means of payment are in constant flux.

1. Introduction

How do Germans pay for their purchases, what costs does this generate and how are payment habits changing? Through regular surveys such as its payment behaviour study,[1] the Bundesbank helps provide answers to these questions. With the costs of payment media having figured more prominently in discussions over past years, in 2014 the Bundesbank published an overview and initial estimates of the costs and benefits of cash and cashless payment instruments.[2] That study described the evolution of cash and cashless payment transactions in Germany and abroad and provided a critical overview of previous cost studies at that time. The study also estimated the economic importance of payment instruments. The authors of the 2014 study highlighted that employees' time is also a key cost factor, with a large share of the costs in the retail sector found to be attributable to the payment process at the point of sale (POS). Only a survey could provide the data needed to assess this time aspect in precise terms and put a price on it, however.

With a view to analysing these points in greater depth and, in particular, to delivering more granular answers to the questions regarding the costs per transaction as well as the cost volumes arising for the economy as a whole, the Bundesbank collaborated with the EHI Retail Institute to conduct a study for 2017 on the costs of means of payment in the retail sector.[3] The work focused on ascertaining precisely which factors determine costs. Three cost components were identified for cash payments, and four for cashless payments. The first cost component represents the outlay for cashier time. Cashier time refers to the length of time spent on

1 See Deutsche Bundesbank (2018).
2 See Krüger and Seitz (2014).
3 The study looked at the costs for the stationary retail sector in the narrower sense. That includes, for example, food retailers, furniture stores and drugstores (see *Figure 3*). Stationary retail trade in the broader sense comprises establishments with retail elements such as pharmacies, automotive accessories suppliers, cash-and-carry supermarkets, hair salons, motor vehicle traders and petrol station shops as well as trade businesses in the form of bakeries and butchers' shops. However, stationary retail trade in the broader sense is typically not deemed to be part of the retail sector and is not taken into account in the analyses which follow. See Cabinakova, Horst and Knümann (2019).

a payment process at the POS and the portion of staff costs arising from the employee's time spent working at the POS. The second cost component comprises POS background costs, which cover expenses relating to all background activities, such as cashing up, sorting receipts for card payments, and depositing and re-counting change. In the case of cash payments, cash removal and supply costs constitute the third cost component. For card payments, the third component is transaction costs. The fourth component, reflecting the specificities of cashless payments, covers terminal costs, including those for maintenance and updates to software.

In order to estimate the economic dimensions of these costs, the study took account of volume data from the retail sector, measured the length of payment transactions at retail POS and employed findings from in-depth interviews with retailers. The costs of cash payment as determined were then compared against those of the most common cashless methods. Breaking costs down into fixed and variable costs, running scenarios with altered average variables and estimating cost functions and developments also made it possible to analyse changes in payment behaviour. This is particularly relevant considering the growing use of contactless card payments.

It should be noted that the following remarks offer a partial insight into the costs of payment methods. Payment instruments generate costs not just for retailers but also for other agents within an economy, such as the central bank, cash-in-transit companies, credit institutions and households. A portion of these costs is already accounted for by determining the costs borne by retailers. Precisely calculating the costs incurred at a macroeconomic level is far from straightforward, however. Information on time outlay and other expenditure incurred by all actors would need to be broadly available, and this is not yet the case. Examination of the costs arising in the retail sector is therefore a first step towards ascertaining part of the economic costs and shows that calculating specific costs is a difficult and very much assumption-based exercise. The Bundesbank is committed to ensuring that citizens remain free to choose how they wish to pay and maintains a neutral stance on specific means of payment.

2. The structure of the German retail sector

Germany's retail sector encompasses around 355,000 stores, which in 2018 recorded gross sales of €430 billion.[4] Just under 12% of stores fall into the organised food retail category. With a sales share of just under 42%, this group has by far the highest sales in the retail sector.[5] Relative to the number of stores, drugstores and perfumeries as well as furniture and furnishings stores also have disproportionately high shares of sales. One of the reasons for this is likely to be that these branches include a number of large chains with high sales.

In terms of the total number of transactions in the German retail sector in 2018, just under 76% were settled in cash and roughly 23% by card[6] (see *Figure 1*).[7] The vast majority of all card payments can be attributed to the girocard system (14.3%), followed by (SEPA) electronic direct debiting (4.9%) and credit cards (2.9%).[8] Invoice/finance purchases (0.6%) and other cashless options (0.5%), such as voucher transactions, figure comparatively rarely. Extrapolated for the German retail sector as a whole, this amounts to 15.2 billion cash purchases, 4.6 billion card-based payment processes and a further 220 million other cashless transactions.

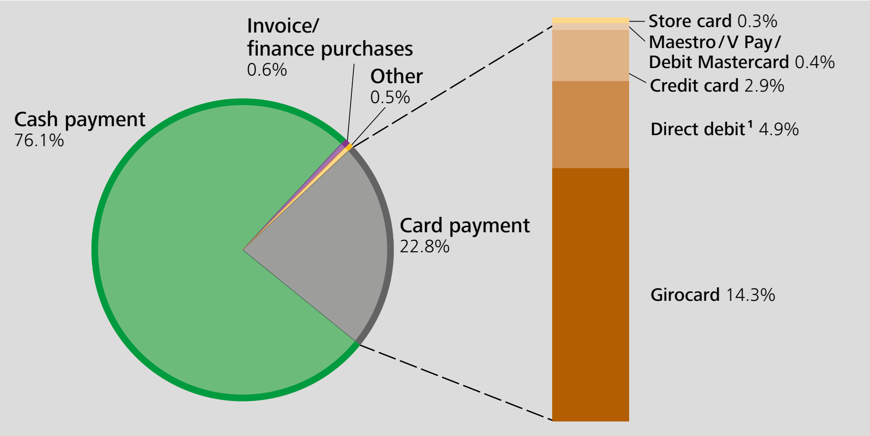
As a share of the €430 billion in total sales recorded for the German retail sector, cash accounts for 48.3%, while card payments make up 48.6% (see *Figure 2*).[9] The largest share of card payment sales is accounted for by girocard (30.1%), followed

4 See EHI Retail Institute (2019).
5 See Cabinakova, Horst and Knümann (2019).
6 Including contactless payments.
7 See EHI Retail Institute (2019).
8 Including payments by smartphone involving a linked credit card.
9 See EHI Retail Institute (2019).

Transactions in the retail sector, by payment method (%)

Figure 1

20 billion transactions

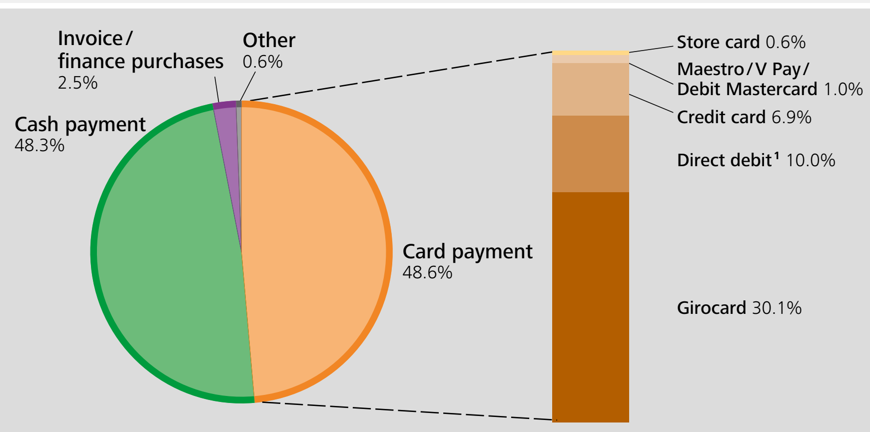


Source: EHI Retail Institute (2019). **1** Electronic direct debit (SEPA direct debit).

Sales in the retail sector, by payment method (%)

Figure 2

€430 billion in total



Source: EHI Retail Institute (2019). **1** Electronic direct debit (SEPA direct debit).

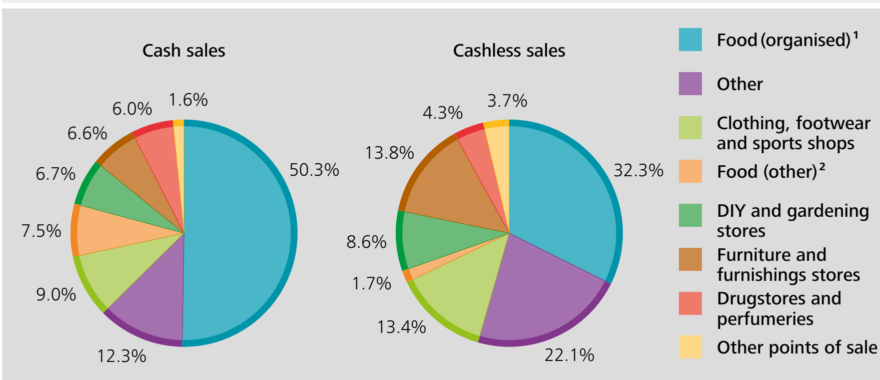
by electronic direct debiting (10.0%) and credit cards (6.9%). The share of invoice/finance purchases amounts to 2.5%, while other cashless payment instruments represent a sales percentage of 0.6%. Extrapolated for the German retail sector as a whole, this is equivalent to sales of €208 billion from cash transactions, €209 billion from card payments and €13 billion from other cashless transactions.

The organised food retail branch alone generates around 50% of cash sales and around 32% of cashless sales (see *Figure 3*),[10] giving food retail a disproportionately high percentage of cash sales. The same is true of drugstores and perfumeries. Besides organised food retail, a high percentage of cashless sales is attributable to furniture and furnishings stores as well as clothing, footwear and sports shops. This distribution reflects variation in payment behaviour, which is partly due to differences in average payment amounts.

Cash sales and sales using card-based payment methods as well as other cashless transactions in the retail sector

Figure 3

€410 billion in total



1 Including supermarkets and discounters in the food retail sector. **2** Smaller, often independently run outlets in the food retail sector, such as kiosks or greengrocers' shops.

10 See Cabinakova, Horst and Knümann (2019).

The German retail sector's annual sales of €430 billion is generated in over 20 billion transactions. This is equivalent to around 220 purchases per capita and just under 470 purchases per household per year.[11] A total of 725,000 POS are in operation in around 355,000 retail establishments. These POS are generally settled (or "balanced") on a daily basis. Overall, this results in 34 million cash removals[12] per year, which is equivalent to around €6,170 per removal[13] and to cash registers being settled an average of 6.6 times per removal process. On average, each store thus has cash removed from its premises around 1.9 times a week.[14]

3. Payment times in the German retail sector

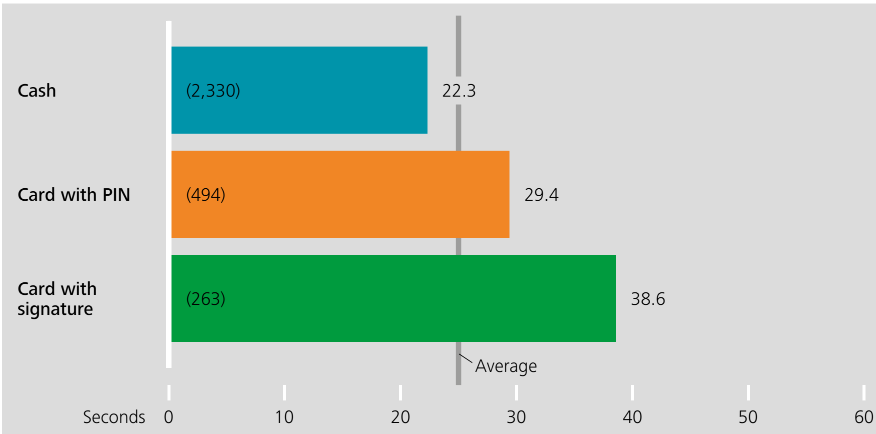
Employees' working hours are a major factor when calculating the costs of payment media borne by the retail sector. The payment process at the POS accounts for a large portion of these working hours. For this reason, a total of 3,125 time measurements were carried out at the point of sale on 17 days between May and November 2017 at 15 selected businesses in six sectors based on the results of a structural analysis of the retail sector. According to these measurements, payment with cash lasts 22.3 seconds on average. Card payments where a PIN is entered last 29.4 seconds on average, while card payments with a signature take 38.6 seconds (see *Figure 4*). Each time measurement started as soon as the cashier stated the purchase amount. The time was stopped when the voucher and/or the payment receipt was handed over, change was handed over or the till was shut. It was essential to ensure that the cashier was ready for the next customer before starting the new time measurement. Only a small number of "contactless" payments were able to be measured in the aforementioned study, and as such they

11 See Cabinakova, Horst and Knümann (2019).
12 Meaning when cash is paid in to commercial banks or the Bundesbank.
13 Once a cash register has been reconciled, the day's takings are removed and a fixed or variable amount of change remains in the cash drawer.
14 See Cabinakova, Horst and Knümann (2019).

Duration of payment transactions, by payment method*

Figure 4

Number of measurements in brackets



* Data source: 3,125 time measurements excluding 38 other payments.

cannot be considered to be representative. A cost simulation that takes contactless card payments into account was carried out nonetheless.

The amount to be paid influences how long a payment transaction takes. The latest studies show that the duration of a payment increases as the amount paid rises for all of the payment media analysed.[15] While payments up to €10 generally take just over 18 seconds, payments over €50 last longer than half a minute on average (see *Figure 5*). Small amounts below €10 paid with cash even take less than 18 seconds on average, while amounts between €50 and €100 require over 32 seconds. For cash payments, the payment duration shows a linear increase as the payment amount rises. This is likely to be attributable, amongst other things, to the fact that customers are more likely to know or estimate the total of smaller pur-

15 See Cabinakova, Horst and Knümann (2019).

chase amounts and have the cash ready for payment. As a rule, smaller amounts also generally need less cash. With medium und higher amounts, the customer generally has to wait to find out the final total, then decide which payment instrument to use and, if applicable, find the appropriate banknotes and coins. Customers and cashiers also tend or are required to check payments involving higher amounts more closely to avoid any mistakes or to identify counterfeit money, for instance.

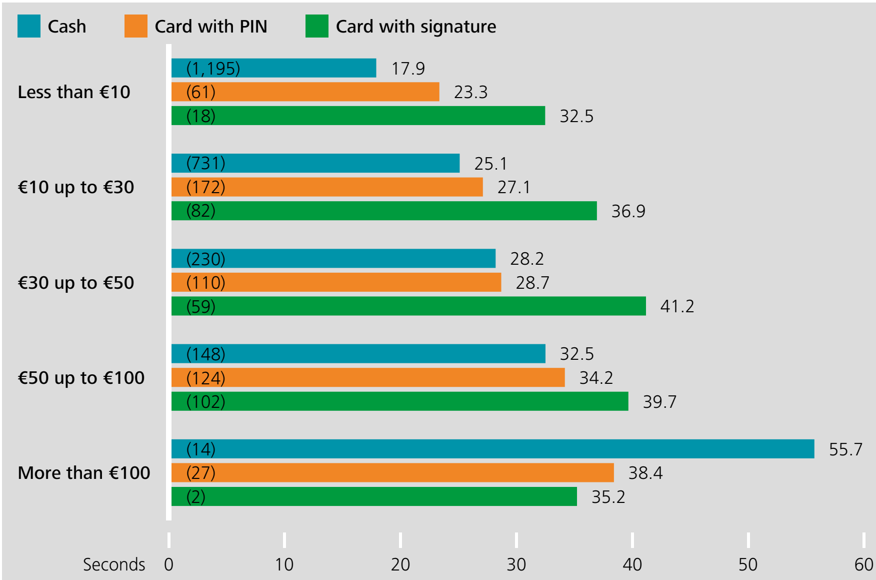
Compared with cash payments, the duration of a payment by card with PIN increases less strongly as the payment amount goes up. Small amounts of below €10 generally take just under 23 seconds, whereas amounts of between €50 and €100 need more than 34 seconds. It is only for purchase amounts of more than €100 that paying by card with PIN is much quicker than a cash payment. Payments by card with signature take the longest for all payment amounts. While payments of below €10 take the shortest amount of time (32.5 seconds) for this payment method, too, there is no clear linear correlation between payment duration and purchase amount. Amounts between €30 up to €50 have the longest payment duration of 41.2 seconds. A payment duration that tends to increase as the purchase amount rises could be attributable to the fact that customers and cashiers tend to check payments involving higher amounts more closely in order to avoid any payment errors at the checkout. Nevertheless, payment durations fluctuate less strongly for card payments than for cash payments across all payment amounts.

4. Point-of-sale processes in the retail sector

At the start of each cash register shift in the retail sector, change is usually either deposited into the cash drawer or the change that is already in the cash drawer is recounted. In some cases, additional rolls of coins are deposited. If the same drawer is to be used by the same cashier who counted it at the end of the previous day, this step is not necessary. Although, in most cases, cash registers are balanced in-

Duration of payment transactions, by amount* Figure 5

Number of payments in brackets



* Data source: 3,125 time measurements, excluding other payments (38) and withdrawals (12).
Deutsche Bundesbank

dividually at the end of the day or shift, the detailed processes vary immensely from establishment to establishment. The differences depend mainly on:

– the type and scope of the cash office/cash office functions;
– the type and scope of the dual control principle;
– the type and scope of the two-person principle when transporting cash internally;
– whether cashiers share a cash drawer over the course of the day or whether each cashier has their own cash drawer;
– whether cash is counted at the cash register or in the cash office;
– whether cash is counted at the end of the day or the next morning;

- whether cash is counted manually or there is single-denomination weighing of all denominations;
- whether there are intermediate cash drops;
- whether exact daily takings are pulled from the cash register or only surplus banknotes;
- the cashier's knowledge of how much money should be in the cash register when balanced;
- rules on personal liability and cash shortages.

Where settlement takes place at the end of the day, all cash holdings in the drawer are counted and added up. This process usually takes place either directly at the cash register (often after opening hours) or, because of the added security, in the cash counting room. After that, the branch manager/cash office confirms the closing balance. If there are no discrepancies, the cashier pays out their daily takings, usually in the presence of a second person (head cashier/cash office employee/branch manager), and receives a fixed or variable amount of change in return. Once the cash register has been reconciled, the daily takings are removed and a fixed or variable amount of change remains in the cash drawer. There are a number of variations on the usual process, stemming mainly from the differences outlined above.

Depending on the volume of cash takings, all cash takings are prepared for removal either at the end of the day or after a number of days (i.e. merged, re-counted, usually put into safebags) before they are collected by an employee from the cash-in-transit (CIT) company, who initially merely confirms receipt of the numbered safebags. Cash drops made at intermediate intervals are often packed into safebags in advance and stored in the safe in the meantime. For this purpose, some enterprises have deposit slot safes that can only be opened by the CIT company.

Safebags are usually taken to the CIT company's cash processing centre to be opened, checked and counted for each of the enterprise's branches individually and then merged for deposit and subsequently deposited at the Bundesbank. However, some of the larger retail chains do not have cash offices at their stores; instead, the CIT company receives one safebag per cash register or cashier. Retailers with very high daily takings use the Bundesbank's direct deposit process. In this case, the CIT company merely transports the cash from the retailer to the Bundesbank branch without processing it further. The cash is usually transported in sealed P-boxes or containers. The majority of retail stores deposit their cash takings themselves, with the proprietor or a staff member paying in cash holdings to a bank at regular intervals. These are usually stores where holdings of cash are so low that it is not worth hiring a CIT company to collect them.

The heterogeneity of point-of-sale preparation and settlement processes, including intermediate cash drops and replenishing change, makes it difficult to clearly define an average scenario for evaluating the individual processes (point-of-sale preparation and settlement, cash drops, ordering change, etc.) or function groups (cash register, cash office) which would enable a reliable extrapolation for the entire retail sector. This is further hampered by the fact that the quantity structures required for such an extrapolation are extremely difficult to determine or estimate.

The results are therefore more reliable if the extrapolation takes cash register settlement as the reference variable. This means that the times are added up for all background activities that occur on average during the settlement process or for which a proportion of the activity can be assigned to the process in question. This includes the following activities:

- depositing and re-counting change at the beginning of each shift, with dual control if applicable;
- depositing additional rolls of coins;

- if applicable, preparing a replacement point of sale (emergency point of sale), on a pro rata basis;
- time spent en route between the cash office and the checkout area;
- intermediate cash drops for cash registers, including time spent en route, generally on a pro rata basis according to frequency;
- emptying the cash depository/safe at intermediate intervals, including time spent en route doubled if the two-person principle is in effect;
- replenishing change at cash registers at intermediate intervals, including time spent en route, generally on a pro rata basis according to frequency;
- ordering change, generally on a pro rata basis according to frequency;
- receiving change, including counting and depositing, generally on a pro rata basis according to frequency;
- time spent en route between the checkout area and the cash office;
- manually counting daily takings/weighing daily takings by denomination;
- settling the cash register, including counting and depositing into the safe and entry into the cash book;
- reconciling cash register discrepancies, generally on a pro rata basis according to frequency;
- regular or irregular cash checks (cash registers);
- regular or irregular cash checks (safe);
- reconciling cash office (safe) discrepancies, generally on a pro rata basis according to frequency.

5. Costs of payment instruments

The interviews with retailers from different branches and of varying sizes conducted in addition to the time measurements aimed to determine the outlay of time for upstream and downstream POS activities, including change supply and cash removal. Additionally, an average staff cost rate and the costs of back office activities relating to payment procedures was calculated from interviews with ten large (chain) and 20 small (independent, owner-operated) retailers. Another objective of the interviews was to assess retailers' costs arising from external service providers such as cash-in-transit (CIT) companies or banks.

Adding together the respective overall expenditure for the three costs items, cash payments cost the retail trade €3,775 million overall annually. In terms of the €210 billion in cash sales and 15.6 billion cash transactions, a cash payment costs on average €0.24 per transaction, corresponding to a cash sales-related charge of 1.80% (see *Figure 6*).

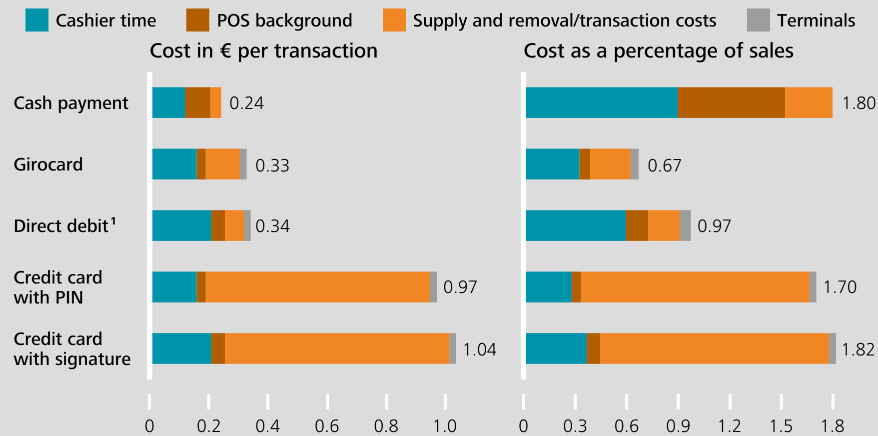
Adding together the overall expenditure of the four cost items for cashless payment media gives the following costs: For girocard payments with PIN, the retail sector incurs overall annual costs of around €675 million. In terms of the 2.1 billion transactions and sales of €101 billion, a girocard payment with PIN costs on average €0.33, which corresponds to a sales-related charge of 0.67% (see *Figure 6*). Debit card payments result in overall annual costs of around €535 million for the retail sector. Accordingly, a debit card payment costs €0.34 on average (1.6 billion transactions), or 0.97% of the sales (total sales of €55 billion). Credit card payments with PIN result in overall annual costs of €128 million. In terms of the approximately €8 billion in sales and 132 million transactions, a credit card payment with PIN costs €0.97 on average, or 1.70% of sales. Credit card payments with signature generate overall annual costs of €319 million. With €17.6 billion in sales and 308 million transactions, a credit card payment with signature costs €1.04 on average, which corresponds to a sales-related charge of 1.82%.

6. Cost analysis for cash and cashless means of payment

For cash payments, the total cashier time outlay is obtained by multiplying the measured times (average cash payment = 22.3 seconds) by the calculated hourly wage of €19.50 and the respective annual transactions. This results in total costs for cashier

Cost overview of payment methods in retail

Figure 6



1 Electronic direct debit initiated by signature during payment process.

times of €1,882 million per year, which is equivalent to €0.12 per cash transaction and 0.90% of cash sales. The total outlay for back-end processing is calculated by multiplying the average 18 minutes[16] of time spent per POS settlement by the hourly wage of €19.50 and the annual number of POS settlements and transactions. Overall, the background costs for cash handling thus amount to €1,315 per year, €0.08 per transaction and 0.63% of cash sales. For cash removal and change supply, with 34 million removal processes annually costing an average of €17 each, a total of €578 million is spent per year. This is equivalent to €0.04 per cash transaction and 0.28% of cash sales.

16 Cash handling accounts for 17 minutes; measured in units of time, 1 minute is attributed to costs for write-downs of safes, cash counting machines, cash scales, banknote verification machines, costs for safebags and insurance.

The total cashier time outlay for cashless payment methods is also obtained by multiplying the measured times (payment with card + PIN = 29.4 seconds; payment with card + signature = 38.6 seconds) by the hourly wage of €19.50 and the respective transactions per payment type conducted annually. According to the EHI Retail Institute, card payment terminals are already in place at around 85% of tills in the retail sector,[17] which means a base of around 616,000 payment terminals overall. Taking into account the limited life cycle of a device, total annual costs per terminal of €150 are applied at the same rate for all payment procedures.[18] 616,000 terminals therefore incur annual costs of €92.4 million. The terminal costs are broken down on the basis of their actual use of the individual payment procedures, which means that the same hardware costs are charged for each transaction.

The processing of card payments is not completely automated in most cases. It is important to consider staff time here, too. For example, there are still receipts from card payments which when cashing up at the end of the day are often archived or sorted, as appropriate. Furthermore, manual intervention is required if terminals crash, statements from card operators and service providers must be checked for accounting purposes and software updates conducted. These costs vary greatly depending on the organisational structure. Alternatively, two minutes per day and terminal are applied for payments which are virtually paperless (girocard and credit card with PIN) and three minutes for payments which still mainly involve paper (SEPA direct debit, credit card with signature).

The transaction fees with their respective components differ among cashless payment procedures. Only the network operator fees are relatively consistent: for girocard and direct debit, 0.05% of the transaction value is payable on average and

17 See Cabinakova, Horst and Knümann (2019).
18 See Cabinakova, Horst and Knümann (2019).

Cost overview of all payment methods in comparison

Cost item	Cash	Girocard
Sales (in € billion)	210.00	101.00
Transactions (in million)	15,579	2,060
Average receipt amount	€13.48	€49.03
Average payment duration (in seconds)	22.3	29.4
Total outlay POS background	**€1,314,787,500**	**€62,991,952**
Per transaction	€0.084	€0.031
As a percentage of sales	0.626%	0.062%
Total outlay cashier time	**€1,881,934,167**	**€328,055,000**
Per transaction	€0.121	€0.159
As a percentage of sales	0.896%	0.325%
Total terminal costs per year	**/**	**€46,901,786**
Per transaction	/	€0.023
As a percentage of sales	/	0.046%
Removal and change costs p.a.	**€578,000,000**	**/**
Per transaction	€ 0.037	/
As a percentage of sales	0.275%	/
Transaction costs	**/**	**€ 237,354,230**
Per Transaction	/	€0.115
As a percentage of sales	/	0.235%
∑Total costs	**€3,774,721,667**	**€675,302,968**
∑Total costs (in € million)	**€ 3,775**	**€ 675**
Per transaction	€0.242	€0.328
As a percentage of sales	1.797%	0.669%

Table 1

Direct debit	Credit card – PIN	Credit card – signature	∑Total costs
54.80	7.53	17.57	390.90
1,560	132	308	19,640
€35.13	€57.05	€57.05	/
38.6	29.4	38.6	/
€71,568,482	**€4,037,196**	**€14,130,188**	**€1,467,515,318**
€0.046	€0.031	€0.046	/
0.131%	0.054%	0.080%	/
€326,170,000	**€21,021,000**	**€64,397,667**	**€2,621,412,955**
€0.209	€0.159	€0.209	/
0.595%	0.279%	0.367%	/
€35,517,857	**€3,005,357**	**€7,012,500**	**€92,437,500**
€0.023	€0.023	€0.023	/
0.065%	0.040%	0.040%	/
/	**/**	**/**	**€578,000,000**
/	/	/	/
/	/	/	/
€99,736,000	**€100,149,000**	**€233,681,000**	**€670,920,230**
€0.064	€0.759	€0.759	/
0.182%	1.330%	1.330%	/
€532,992,339	**€128,212,553**	**€319,221,355**	**€5,430,286,003**
€ 533	**€ 128**	**€ 319**	**€ 5,430**
€0.342	€0.971	€ 1.036	
0.973%	1.703%	1.817%	

for credit card payments around 0.06% on average. In most cases, this is not a percentage fee, but a fixed amount which is applied for each transaction (e.g. €0.01 or up to €0.28). There is also an authorisation fee for girocard payments with PIN of around 0.19% of sales on average. No authorisation fees are charged for direct debit transactions. However, payment defaults and the processing outlay for defaults or corresponding insurance premiums should be taken into account. An average insurance and default risk of 0.132% was calculated overall, which also includes internal processing costs (dunning letters, bank charges or similar, where applicable) for temporary payment defaults. In the case of transaction fees for credit card payments, a weighted average fee of 1.33% of the transaction value was calculated. This includes interchange fees, scheme fees and Merchant Service Charges (MSC) as well as network operator fees.

The payment procedures above calculated in this way cost German retailers €5,430 million in total per year (see *Table 1*). Of this, cash payments make up €3,775 million per year and all card-based payments considered (girocard, debit, credit card) make up €1,656 million, and while both payment media have similar percentages of sales, with each at just under 50%, cash payments had a significantly larger proportion of the transactions. This does not take into account sales of €13 billion per invoice/finance purchases/voucher and around €6 billion in sales from other card payments (store cards, maestro, VPAY). When these are included,[19] with gross sales of €410 billion and 20 billion transactions, total costs in retail amount to around €5.7 billion annually.

The results show that, in terms of transactions, cash is currently the most cost-efficient payment method for retailers. Looked at in terms of sales, the relationship is

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19 For the calculation of the total costs for invoice/finance purchase/voucher and other card payments (store cards, Maestro, VPAY) a cost component of 1.76% of sales is assumed, see Cabinakova, Horst and Knümann (2019).

reversed: in this case girocard payments are the cheapest payment method for retail trade. Direct debit payments and credit card payments with PIN are also cheaper than cash payments in terms of sales. It becomes clear that the costs for back-office activities are relatively high for cash payments, while for card payment systems, in particular credit card payments, the transaction costs account for a relatively large proportion of the costs. These direct comparisons have only limited informative value, however, as the various payment methods entail different payment amounts, amongst other things.

7. Contactless payments

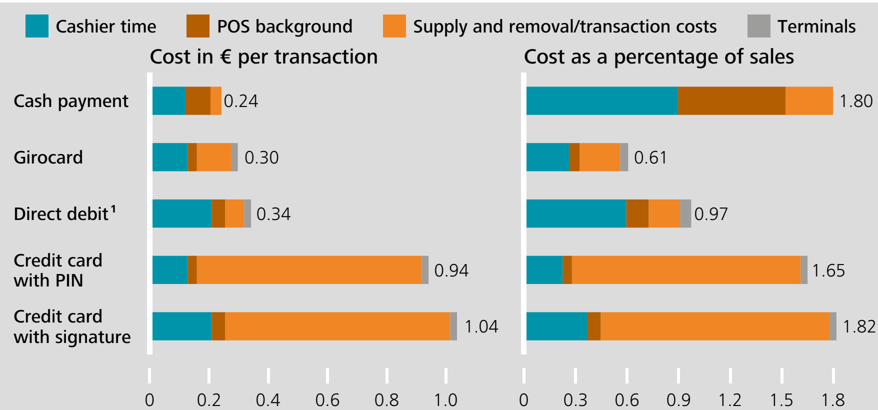
Recent times have seen a marked increase in contactless payments. These are payments made by holding a card, smartphone or another device equipped with near-field communication (NFC) technology[20] up against a payment terminal. Verification, for example by entering a PIN, is not required up to a certain amount. This threshold is currently set at €25 in the German retail sector. More than 20% of all card payments are now estimated to be contactless, and this proportion is rising.[21]

The contactless method and omission of the verification step are meant to speed up the payment process. For example, the card is not inserted into the reader when making a contactless card payment. However, little is known as yet in terms of precisely how long the average contactless payment takes. Studies to date suggest that–when the operation is carried out correctly–average payment times of between ten and 15 seconds are to be expected, providing verification is not required. At present, it is mainly credit cards that feature NFC technology in Germany. However, by the start of 2020, the intention is for all girocards issued by banks and savings banks to be NFC-enabled, too.

20 NFC (near-field communication) is the technical standard for contactless payments.
21 See EHI Retail Institute (2019).

Simulation for contactless card payments: cost overview of payment methods in retail

Figure 7



1 Electronic direct debit initiated by signature during payment process.

Only an extremely small and, therefore, probably no longer representative sample of contactless card payments were captured in the Bundesbank's cost study in 2017. This is due to the fact that contactless payments have only recently become more commonplace. Simulations for contactless card payments are carried out, so as nevertheless to consider potential costs associated with this new form of payment. In order to derive an upper limit for the maximum time saving achievable, it is assumed that all girocard and credit card payments so far carried out with PIN shift to contactless and that no verification step is involved for payments of amounts less than €25.

Around 40% of the girocard and credit card payments currently made with PIN are for amounts under €25. For these payments, it is assumed that the average cashier time is cut in half, reducing from just under 30 seconds to 15 seconds, due to the omission of the verification step. Payments over €25 still have a cashier time of 29.4 seconds. It is unclear to what extent cashier times for payments in excess of

€25 (contactless but including verification) change as a result of contactless payment. Given the lack of empirical data in this area, the average cashier time as it stands now is assumed. Based on these assumptions, the new average payment duration for girocard and credit card payments previously carried out with PIN would then be just under 24 seconds, giving card payments an average duration comparable to that of cash payments. The cashier time costs for girocard and credit card payments with PIN would fall in this scenario.

It is also conceivable that progressive uptake of contactless payment would result in migration flows. It is possible, for instance, that relatively small amounts paid using cash up until this point would instead be paid using a contactless girocard or credit card in this scenario. A portion of current direct debit or credit card payments with signature would probably also be carried out using a contactless option. This would bring about changes in terms of cost structures and transaction and sales shares. For the sake of simplicity, it is therefore assumed in this simulation that only girocard and credit card payments currently carried out with PIN shift to contactless.

Overall, cash payments continue to have the lowest costs per transaction. Contactless girocard or credit card payments become even cheaper than direct debit and credit card payments with signature due to the faster payment time (see *Figure 7).* Looked at in terms of sales, the relationship is reversed: contactless girocard payments have the lowest costs, followed by electronic direct debit, contactless credit card payments, cash payments and credit card with signature payments.

8. Costs depending on the price

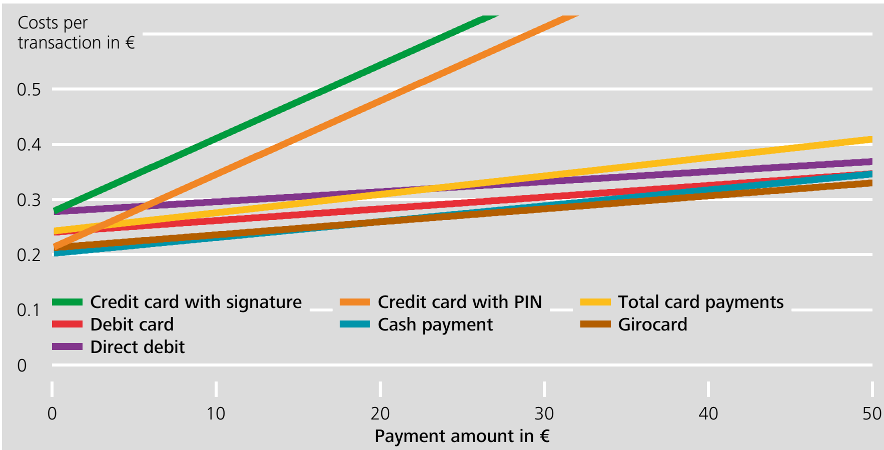
The aforementioned cost calculations are fundamentally based on average values–average payment amounts or transaction percentages, for instance. If these variables change, different cost components also change, and with them the total cost of the means of payment in question. For example, transaction fees for card payments depend on sales or, to be precise, the average payment amount. Other cost components, meanwhile, are generally incurred irrespective of the number or value of transactions, such as the cost of purchasing terminals. It is therefore conceivable that different payment amounts may see different means of payment generating the lowest costs. It is often assumed that cash payment for transactions involving relatively low payment amounts gives rise to fewer costs than card payment, while the opposite is true when it comes to higher payment amounts, with card payment working out less costly than cash payment.

When seeking to ascertain the costs associated with each payment method for different payment amounts, it is helpful to differentiate between fixed and variable costs. The variable costs can be further broken down into transaction-dependent and sales-dependent costs.[22] Transaction-dependent costs give rise to the same amount every transaction, whereas sales-dependent costs are also contingent on sales or the payment amount. The three cost components for cash payments are cashier time, background costs and cash supply and removal. For cashless payments the following components are duly allocated: cashier time, background costs, transaction costs and terminal costs.

Figure 8 shows the costs of a transaction depending on the payment amount for cash payments and each of the card payment methods. Owing to their relatively low fixed costs, cash payments have the lowest costs on average for small payment amounts. The costs are higher in the case of payments by girocard or credit card with PIN; payments by direct debit and credit card with signature incur significantly higher costs. Using the above-mentioned estimates as a basis, the costs of a girocard transaction are lower than those of a cash transaction only when the payment amount is €19.42 or higher. Owing to the high sales-dependent costs, the costs of a transaction by credit card (PIN or signature) increase much more sharply

22 See Krüger and Seitz (2014).

Cost comparison of different payment procedures Figure 8



than those of the other payment methods and, for most payment amounts, are higher than all the other observed means of payment.

When comparing a cash payment with a cashless payment method, such as girocard, it should be borne in mind that retailers, if they accept cashless payments, frequently offer more than one cashless payment method. Retailers then generally have no say in whether a customer uses a method of payment that is either more favourable or more costly for them. The costs of cashless payments should, in addition, therefore also be compared with some or all of the costs of cashless payment methods. Taking into account the transaction percentages of the individual card payments, the average costs of all card payments per transaction are invariably higher than the costs of a cash transaction. Some retailers–say, owing to the comparatively high transaction fees for credit card payments–accept only payments by debit card at their payment terminals. Considering the transaction percentages of girocard and direct debiting, it is only at an amount of €51.67 or higher that payments by debit card involve lower costs per transaction than cash payments. Accordingly, payment behaviour in Germany, where payment amounts up to €50 are mostly paid in cash and amounts higher than €50 are predominantly paid by debit card, appears to be favourable payment behaviour in terms of the overall costs.

9. Summary

Payment habits change, albeit slowly. This not only entails changes for the retail sector–the main sector where citizens in Germany shop–but also different cost structures and total economic costs, which remain unexamined at this stage. The discussion regarding the use of an "ideal" means of payment in terms of efficiency, speed, security and also data protection, to name just a few aspects, goes far beyond the scope of the calculations outlined here. This present study allows the Bundesbank to calculate granular costs of the various payment instruments in the retail sector, aggregated at the national level, and to contribute to the factual discussion about the advantages and drawbacks of the various payment instruments.

The study provides three key findings: First, cash is used in three out of four cases in Germany to pay at the POS. All other payments are made in cashless form. Second, card payments average around 29 or 39 seconds in duration, depending on whether the payment involves a PIN or a signature. Cash payments are completed in just under 22 seconds on average. Third, cash is the cheapest means of payment per transaction, ahead of debit card payments and far ahead of credit card payments, while card payments, especially girocard payments, are cheaper for the retail sector than cash payments.

One of the strengths of this study lies in making transparent the cost structures of various payment procedures. This provides an overview of the points where costs arise–stemming, for example, from the payment process, background activities or various fees. However, when interpreting the figures, it should be noted that the costs presented are based on average values and that various payment structures must be taken into account.

In order to increase the informative value of the data collected, a range of scenarios were simulated using various variables, including greater use of contactless card payments. This type of payment barely registered on the radar when the study was conducted in 2017, but is likely to gain in importance in future studies.

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Arkadiusz Manikowski
Model of banknote migration–case of Poland[1]

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Abstract

This paper outlines a way of use of the Markov Chain model for describing banknote migration between regions in Poland. We show the application of the methodology for estimating one-step transition probabilities for the Markov Chain based on macro data gathered during the project conducted in NBP in the period of December 2015-2018. We have shown the usefulness of state aggregated Markov Chain as a model of banknote migration.

The proven property of the Markov Chain ergodicity shows the existing steady-state of proportions of fit notes in the regions. Some characteristics obtained from the model can be used for quantitative identification of how and why notes migrate between regions. For this purpose, two kinds of mean time were estimated: first passage and recurrence times. Transition probability expressing the attractive

1 This paper should not be reported as representing the views of NBP.

force between regions allows to estimate the Gravity Model for the identification of relevant reasons of note migration. We have also shown how the results obtained can be used for analysis of note migration between countries in the eurozone.

1. Introduction

In this paper we elaborate the migration model of banknotes between regions in Poland. We focused on the low denomination banknote 10 zloty because of the data available, collected during the so-called Note Case project conducted by NBP over the 3-year period up to 2018. The main aim of the project was strictly related to the effect of the extension of life span thanks to note varnishing. During the project data on the location of banknotes was also gathered, which allowed us to make another study on migration.

Knowledge of the scale of banknote migration can be helpful for central banks in such situations as:

- Detection of sources where counterfeit banknotes are introduced into circulation,
- Supporting the management of cash stock in branches of the central bank,
- Identification of banknote emigration (how many notes are abroad?).

Additionally, in the case of monetary unions (like euro area) data on migration can help to estimate the circulation volume of notes in the member states.

The main reasons for banknote migration arranged by expected importance are as follows:

(1) daily commute to work in another region,
(2) networks of companies processing the cash (such as CIT, Post Office),
(3) network of the central bank's branches,
(4) flow of tourists,
(5) business trip,
(6) common road transport.

In the literature we can find a number of studies on the relation between migration and cash in circulation. Most of them deal with coin migration.

For example Grasland, Guérin and Tostain (2002)[2] considered the effect of people's mobility. The authors focused on the dissemination of euro coins in different regions in Europe.

Their analysis was based on data collected during a series of representative surveys conducted in France in 2002. The results obtained allow to explain how different national coins are disseminated in France and which factors influence the migration (e.g. location near the borders, tourism, different kind of travel etc.).

However, the vast majority of the projects were based on voluntary reporting. Well-known examples of these, mentioned among other by Seitz, Stoyan and Tödter in 2009 (cited later), are the Euromobil and Eurodiff projects conducted in Germany, which focused on €1 coins–see Stoyan (2002)[3] and Stoyan et al. (2004)[4], Eurotracer which also includes note migration, and Eurodiffusie conducted in the Netherlands and Belgium (van Blokland et al., 2002)[5]. Bergman et al. (2002)[6] tried to determine among other when 50% of the coins circulating in 12 European countries will be of foreign origin.

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2 Grasland C., Guérin F. and A. Tostain (2002), The circulation of euros as a reflection of people's mobility, Population & Societies, The monthly newsletter of the Institut national d'études démographiques, No. 384, Nov.

3 Stoyan, D. (2002), Statistical Analyses of Euro Coin Mixing, Mathematical Spectrum, 35, 50-55.

4 Stoyan, D., H. Stoyan and G. Döge (2004), Statistical Analyses and Modelling of the Mixing Process of Euro Coins in Germany and Europe, Australian & New Zealand Journal of Statistics, 46, 67-77.

5 van Blokland, P., L. Booth, K. Hiremath, M. Hochstenbach, G. Koole, S. Pop, M. Quant and D. Wirosoetisno (2002), The Euro Diffusion Project, Proceedings of the 42nd European Study Group with Industry, 42, 41-57.

6 Bergman, T., A. Lauri, A. Ruhala and W. Rydman (2002), Euro Coin Diffusion, University of Helsinki, mimeo.

A study on €1 coin migration within the euro area was also conducted by Seitz, Stoyan and Tödter (2009)[7]. For this purpose, consistent data from the above-mentioned online survey projects Eurodiff and Euromobil are available. The authors used inter alia a simple, two-state Markov Chain for description of coin outflow from Germany on the example of €1 denomination. The authors proved that in the long run, the ratio of German €1 coins in Germany is likely to converge to around 50% (in the case of coin population growth in circulation).

Finally, the study presented here strictly pertains to note migration. It was conducted by Fischer (2014)[8], who tried to answer the question: Do immigrants have a higher demand for large-denominated banknotes than natives? He used an econometric model with the demand effect of immigrants relative to natives of a Swiss municipality on banknote order in the same city.

This paper discusses a finite-space, homogeneous, first-order Markov Chain for application to migration of transaction notes. Estimated transitional probabilities were used in the Gravity model to explain why notes migrate.

The paper is organized as follows. Section 2 presents the general problem of banknote migration in Poland, which was quantified during the project conducted in NBP on note varnishing. Section 3 presents the theoretical framework of a migration model as the Markov Chain and the Gravity model. Thereafter, Section 4 shows the main results. The last section offers some conclusions on the usefulness of the presented mathematical model of banknote migration.

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7 Seitz F., Stoyan D., Tödter K-H. (2009), Coin migration within the euro area, Deutsche Bundesbank, Discussion Paper, Series 1: Economic Studies, No. 27/2009, January.

8 Fischer A.M., (2014), Immigration and large banknotes, Macroeconomic Dynamics, 18, 899-919.

2. Migration of notes in Poland–empirical data

The project Note Case (named later as the Project) was conducted in NBP over 3 years (Dec 2015-2018). During this period, data on 10 zloty notes such as, inter alia, location across the country, was also collected. Therefore, it was possible to investigate two issues:

– scale of extension of note lifetime caused by varnishing,
– scale of migration of notes between regions in Poland.

Within the framework of the Project, 2.4 million notes with denomination of 10 zloty and known serial numbers were introduced into circulation in the two regions: Warsaw (region s6) and Poznań (region s4)–see *Figure 1*. The sample of test notes accounts for about 1.6 % of all 10 zloty notes in circulation.

During the Project, micro panel data was collected weekly by BPS M7 sorter machines with the function of serial number reading (SNR).

For the further analysis we decided to aggregate 16 voivodships into seven regions. For aggregation the following criteria were adopted:

– structure of supply network of NBP branches,
– network of sorting (notes returned to branches without a sorter machine are sorted by another one equipped with BPS M7),
– structure of test notes from the point of view of their origin sources.

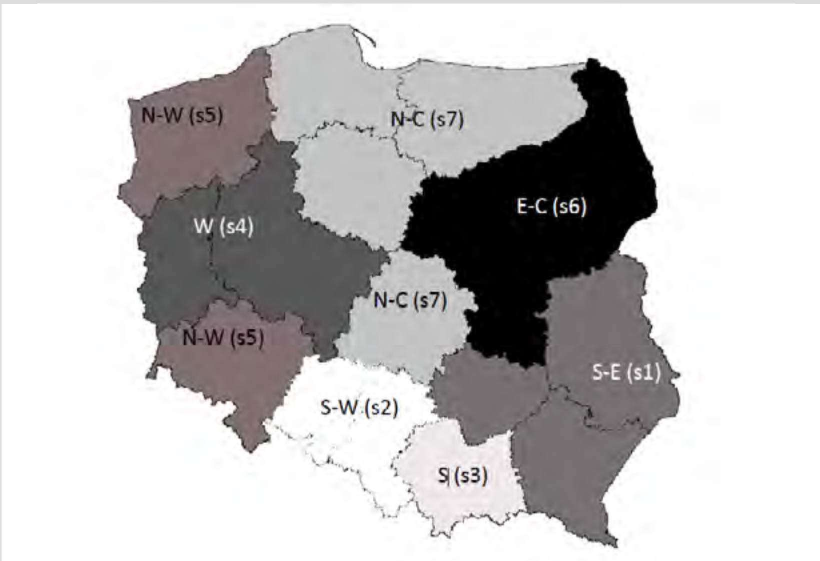
The result of the regions aggregation is shown in *Figure 1*.

We can see two specific features of some regions which can disturb the memoryless property related to the movement of banknotes, which will be considered later:

– the large s7 region consists of four voivodships,
– the s5 region includes two non-neighbouring voivodships,
– every region has at least two neighbouring regions.

Regions in Poland

Figure 1



The above-mentioned features may require data on point of entry into regions for a description of the chance of exit from them. The issue of keeping the memoryless property will be considered later. Based on collected micro data, we can estimate the number of fit notes $v_i(t)$ in the i-th region at time t (considered later as a macro data):

(1) $$v_i(t) = \frac{a_{ti}}{f_{ti}} c_{ti}$$

where $\boldsymbol{\alpha}_{ti}$ means the number of test notes returned to the Bank in the i-th region at time t, f_{ti}- the number of all notes with the same denomination like the test notes returned to the Bank in the i-th region at t time, c_{ti}- the volume of notes in circulation in the i-th region at t time.

Because the Project refers to transaction denomination[9], it was acceptable and advisable to use the GDP of each region for c_{ti} estimation, that is:

(2) $$c_{ti} = \%c_{ti} \cdot C$$

with $\%c_{ti}=\%GDP_{ti}$ as a proportion of notes in circulation in the *i*-th region at *t* time and ***C*** as the number of notes in circulation in Poland.

We can also express f_{ti} as a:

(3) $$f_{ti} = \%f_{ti} \cdot F$$

with $\%f_{ti}$–the fraction of returned notes to the Bank in the *i*-th region (all with the same denomination), and *F*–the number of notes returned to the Bank in the whole regions. Taking into account (1)-(3), we calculated (after some simple mathematical transformations) the proportion $k_i(t)$ of notes in every region using the following formula (4):

(4) $$k_i(t) = \frac{a_{ti} \cdot \frac{\%c_{ti}}{\%f_{ti}}}{\sum_j a_{tj} \cdot \frac{\%c_{tj}}{\%f_{tj}}}$$

According to equation (4), the number a_{ti} of test notes returned to the Bank in the *i*-th region is corrected by the factor $\frac{\%c_{ti}}{\%f_{ti}}$. The advantages of such an approach are as follows:

- If the fraction $k_i(t)$ of returned notes in *i*-region is the same as the fraction $\%c_{ti}$ of notes in circulation, then the proportion $k_i(t)$ is not dependent on the volume of notes in each region.
- If the level of cash inflow into a region is larger than the fraction of notes in circulation (e.g. as a result of the particular cash cycle model implemented in the region) then the value of a_{ti} is corrected in an appropriate way: *in plus* if the inflow is lower or *in minus* if the inflow is greater than circulation.

9 Demand for such banknotes is driven primarily by transaction motive. Their role as a store of value is negligible. Additionally, the probability of their migration abroad is very low too. However, one feature of lower denomination notes such as 10 zloty is that they can disturb the obtained result a little – the risk of their getting lost by the public.

– The proportion $k_i(t)$ is not dependent on cash in circulation in Poland nor on the level of the whole cash inflow to the central bank.

In general, formula (4) allows to take into account not only the distribution of circulation among regions, but also the distribution of returned notes to the Bank. In the case of different cash cycle models in regions and/or various public habits on cash usage, this feature is very important and useful.

3. Model of Migration

3.1. Mathematical model of migration

During a certain period, every note can make the following activities:

– move to another region or
– stay in the same region.

The banknote can also be shredded because of poor quality.

However, we have limited our consideration to fit notes only. Notes can migrate because of some features of the origin and destination regions: population, GDP, tourist attraction, etc. Such a drift can be described by a stochastic process with states as regions and transition probability as a chance of banknote movement during the one step. Because of the weekly frequency of data collection, we define the step as one week.[10]

We can assume that transition between two regions is independent of the whole history, which is suggested by the existing so-called Markov property (the independence of the future from the past)[11].

10 The assumption about a longer length of step could cause the impossibility of registration of bilateral movement of notes between the same regions during the one step.

11 This can be true in the case of not too large, coherent regions with only one neighbour. In the case of another region, dependencies between drift probability to the destination region and point of entry to the source region may appear. Automatically, it could disturb the Markov property. Violation of the Markov property might force us to use variable-order Markov models as an extension of the well-known Markov Chain model – see Begleiter, R.; El-Yaniv, R.; Yona, G. (2004), On Prediction Using Variable Order Markov models, Journal of Artificial Intelligence Research, 22, pp. 385–421.

Geographical location of Markov Chain states in Poland Figure 2

Such features allow us to use the first-order Markov Chain (MC) $(X_n)_{n=1,\ldots,N}$ over a finite set of r states, $\mathbf{S} = \{s_1, s_2, \ldots, s_r\}$ as a model of fit notes migration[12]. *Figure 2* shows the geographical location of MC states in Poland.

In the notation of the MC we can say that if the note is in state s_i (i-th region) then it can move to state s_j (j-th region) at the one step with a probability $\boldsymbol{p_{ij}}$ called transition probability, which is not dependent on the history before state i:

12 It is easy to prove that under the assumption about the same shredding rate in every region, the MC can be used to model the movement of fit notes.

(5) $p_{ij}(n) = P\{X_n = j / X_{n-1} = i\}$

We assumed time-invariant transition probabilities (i.e. $p_{ij}(n) = p_{ij}$) [13]. Thus we can investigate a time-homogeneous Markov Chain with a squared one-step transition probability matrix **P** as a:

(6) $$\mathbf{P} = \begin{bmatrix} p_{11} & \cdots & p_{1r} \\ \vdots & \ddots & \vdots \\ p_{r1} & \cdots & p_{rr} \end{bmatrix}$$

The transition matrix **P** allows us to calculate the probability that MC (note) will be in certain states after *n* steps :

(7) $\mathbf{d}_n = \mathbf{d}_0 \mathbf{P}^n$

with $\mathbf{d}_0$ as the probability vector which represents the starting (initial) distribution (the *i*-th element of $\mathbf{d}_0$ is denoted by $d_{0i} = P\{X(0) = i\}$).

Consideration only fit notes without their loss (e.g. destruction by consumers or migration abroad) suggests the existence of all states (regions) as a transient, which means a lack of absorbing states of MC.

The exclusion of absorbing states (as a model of shredding of unfit notes) is caused by the following two reasons:

- We would like to know if and when the process of migration can reach a stable state;
- Consideration of the absorbing states could disturb the time-homogeneity property. Namely, according to another of our studies, the lifetime of notes as a random variable is not memoryless in contrast to variable with exponential or geometric distribution.

In the analysis of note migration in the long term, stationarity and ergodicity of MC can be interesting: The second kind of MC is very interesting. In the case of the ergodic property of MC the limit of $\mathbf{P}^n$ exists (Frechet theorem):

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13 The assumption seems to be invalid in the situation of, for example, seasonality. But our investigation will show the legitimacy of the adopted assumption.

(8) $\lim_{n\to\infty} \mathbf{P}^n = \mathbf{E}.$

The existing stochastic ergodic matrix **E** (composed of identical rows **e**) means that there is a unique, final state distribution **e** independent on start states $\mathbf{d}_0$[14]:

(9) $\lim_{n\to\infty} \mathbf{d}_n = \lim_{n\to\infty} \mathbf{d}_0\mathbf{P}^n = \mathbf{d}_0\mathbf{E} = \mathbf{e}.$

The above property means that note distribution in the future is constant and is independent of where notes were introduced into circulation at the beginning. The existence of **e** for homogeneous MC is related to some features of transition matrix **P**, which should be regular: irreducible, aperiodic and positive recurrent. The regularity of **P** may be proven by eigenvalues: **P** is regular if it has a unique eigenvalue equal to 1 and other eigenvalues with a norm value below 1.

The transition matrix allows to calculate some characteristics of cash migration such as:

- expected number of steps to reach state *j* from state *i* named Mean First Passage Time (MFPT);
- expected number of steps to reach the same state named Mean Recurrence Time (MRT).

The essential role in the calculation of mean times is played by the so-called fundamental matrix, calculated according to the following formula (10):

(10) $\boldsymbol{Z} = (\mathbf{I} - \mathbf{P} + \mathbf{E})$

The entry z_{ij} of $\boldsymbol{Z}$ and ergodic distribution **e** can be used for calculation of the above-mentioned times according to the following formulas (11) and (12):

- Mean First Passage Time as:

(11) $m_{ij} = \begin{cases} \frac{z_{jj}-z_{ij}}{e_j} & for\ i \neq j \\ 0 & for\ i = j \end{cases}$

14 In the case of a finite, homogenous MC, at least one marginal (stationary) distribution **d** exists: **dP**=**d**.

– Mean Recurrence Time as:

(12)
$$\tau_i = \frac{1}{e_i}.$$

3.2. Estimation of migration model

The main problem with MC estimation pertains to transition probabilities. The estimation of them is relatively simple when individual movements are observed over time (the case of micro data). However, if the time series of observations is sufficiently long, it is possible to estimate the transition matrix from aggregate (macro) data using the GLS technique.

Despite having the micro (individual) data on the serial number of test notes returned to NBP, we decided to use macro data. The reason for such a decision is the natural incompleteness of micro data. We observe only some notes return to the central bank because the weekly value of return rate is well below the level of 1 (as a result of the cash cycle model implemented by the market).

The use of macro data is related to the implementation of the GLS method described below in detail.

According to Lee, Judge, and Zellner (1970)[15], the estimation of transition probabilities relies on the use of the following relations (13)-(14):

(13) $P\{X_t = j\} = \sum_{i \in \mathbf{S}} P\{X_{t-1} = i\} \cdot P\{X_t = j / X_{t-1} = i\}$

or

(14) $d_{tj} = \sum_{i \in \mathbf{S}} d_{t-1i} \cdot p_{ij}$

15 Lee T.C., Judge G.G. and A. Zellner, (1970), Estimating the Parameters of the Markov Probability Model from Aggregate Time Series Data, North-Holland Publishing Co.

where d_{tj} means fraction (proportion) of items (notes) located in *j*-th state (region) at time *t* and can be estimated by $k_j(t)$ defined in (4).

So, we have r econometric models with unknown transition probabilities P:

(15) $k_j(t) = \sum_{i \in S} k_i(t-1) \cdot p_{ij} + \varepsilon_t$

with restrictions due to the interpretation of P as a probability:

(16) $\sum_{i \in \mathbf{S}} p_{ii} = 1$ for $i \in \mathbf{S}$

(17) $p_{ij} \geq 0$ for $i, j \in \mathbf{S}$.

Lee, Judge, and Zellner (1970, Chapters 1, 3)[16] suggest minimizing the sum of squared errors in equation (15) using OLS, subject to linear constraints (Conditional Least Squares method CLS). The OLS is equivalent to solve the quadratic programming problem. The OLS estimator is consistent but not efficient. MacRae (1977)[17] demonstrates how to correct for the heteroscedasticity in the error term and produce a more efficient estimator using an iterative GLS technique for calculating the matrix of transition probabilities **P**. The first step in the procedure is to estimate the transition matrix, and then use this to calculate a consistent estimation of the conditional covariance matrix Ω. The matrix Ω is then used to obtain a subsequent estimation of the transition probabilities, with repetition of the procedure until convergence is reached.

Using the same idea as described above, we adopted a similar approach presented by Podgórska et al. (2002)[18] with 2 steps:

1st step–the problem of minimizing a sum of squares subject to linear constraints on the probabilities as

16 Lee, T. C., G. G. Judge, and A. Zellner, (1970), Estimating… op.cit.

17 MacRae, E. C., (1977), Estimation of Time-Varying Markov Processes with Aggregate Data, Econometrica, Vol. 45, Issue 1 (January), pp. 183–98.

18 Podgórska M, P. Śliwa, M. Topolewski, M. Wrzosek (2000), Łańcuchy Markowa w teorii i w zastosowaniach, SGH, Warsaw.

(18) $$\min_{\mathbf{P}}(\mathbf{y}-\mathbf{XP})^T(\mathbf{y}-\mathbf{XP})$$

with constrains (19)-(20):

(19) $\sum_{j\in\mathbf{S}} p_{ij} = 1$ for $i \in \mathbf{S}$.

(20) $p_{ij} \geq 0$ for $i, j \in \mathbf{S}$.

where

(20a)

$$\mathbf{y} = \begin{bmatrix} \mathbf{y}_1 \\ \mathbf{y}_2 \\ \vdots \\ \mathbf{y}_r \end{bmatrix}, \quad \mathbf{y}_i = \begin{bmatrix} k_i(1) \\ k_i(2) \\ \vdots \\ k_i(N) \end{bmatrix},$$

$$\mathbf{X} = \begin{bmatrix} \mathbf{K} & \mathbf{0} & \dots & \mathbf{0} \\ \mathbf{0} & \mathbf{K} & \dots & \mathbf{0} \\ \vdots & \vdots & & \vdots \\ \mathbf{0} & \mathbf{0} & \dots & \mathbf{K} \end{bmatrix} \text{ with } \mathbf{K} = \begin{bmatrix} k_1(0) & k_2(0) & \dots & k_r(0) \\ k_1(1) & k_2(1) & \dots & k_r(1) \\ \vdots & \vdots & & \vdots \\ k_1(N-1) & k_2(N-1) & \dots & k_r(N-1) \end{bmatrix},$$

$$\mathbf{P} = \begin{bmatrix} \mathbf{p}_1 \\ \mathbf{p}_2 \\ \vdots \\ \mathbf{p}_r \end{bmatrix} \text{ with } \mathbf{p}_i = \begin{bmatrix} p_{1i} \\ p_{2i} \\ \vdots \\ p_{ri} \end{bmatrix}.$$

2nd step–the problem of minimizing a sum of squares subject to linear constraints on the probabilities as

(21) $$\min_{\mathbf{P}^*}(\mathbf{y}^*-\mathbf{X}^*\mathbf{P}^*)^T(\Omega^*)^{-1}(\mathbf{y}^*-\mathbf{X}^*\mathbf{P}^*)$$

with constrains (22)-(23):

(22) $\sum_{j\in\mathbf{S}\setminus\{r\}} p_{ij} \leq 1$ for $i \in \mathbf{S}$.

(23) $p_{ij} \geq 0$ for $i \in \mathbf{S}, j \in \mathbf{S}\setminus\{r\}$

where

(23a)

$$\mathbf{y}^* = \begin{bmatrix} \mathbf{y}_1 \\ \mathbf{y}_2 \\ \vdots \\ \mathbf{y}_{r-1} \end{bmatrix}, \quad \mathbf{X}^* = \begin{bmatrix} \mathbf{K} & \mathbf{0} & \dots & \mathbf{0} \\ \mathbf{0} & \mathbf{K} & \dots & \mathbf{0} \\ \vdots & \vdots & & \vdots \\ \mathbf{0} & \mathbf{0} & \dots & \mathbf{K} \end{bmatrix}_{N(r-1)\mathrm{x}\, r(r-1)}, \quad \mathbf{P}^* = \begin{bmatrix} \mathbf{p}_1 \\ \mathbf{p}_2 \\ \vdots \\ \mathbf{p}_{r-1} \end{bmatrix},$$

$$\mathbf{\Omega}^* = \begin{bmatrix} \mathbf{\Omega}_{11} & \mathbf{\Omega}_{12} & \dots & \mathbf{\Omega}_{1(r-1)} \\ \mathbf{\Omega}_{21} & \mathbf{\Omega}_{22} & \dots & \mathbf{\Omega}_{2(r-1)} \\ \vdots & \vdots & & \vdots \\ \mathbf{\Omega}_{(r-1)1} & \mathbf{\Omega}_{(r-1)2} & \dots & \mathbf{\Omega}_{(r-1)(r-1)} \end{bmatrix}_{N(r-1)\mathrm{x}N(\mathrm{r}-1))}.$$

As we can see, asterisk "*" means limitation in the analysis to r-1 states because of the singularity of variance-covariance matrix Ω of residuals for model (18).

Submatrix Ω_{ij} is estimated at the end of the 1st step using residuals of model (18)-(20):

(23b) $$\mathbf{\Omega}_{ij} = \frac{1}{N-r}\mathbf{e}_i^T\mathbf{e}_j \cdot \mathbf{I}_{N\mathrm{x}N}$$

with $\boldsymbol{e}_j$ as a residual of j-th part of model (18).

It is worth noting that Kalbfleisch and Lawless (1984)[19] show how to estimate transition probabilities in the case of the change of individual population over time. Kelton and Kelton (1984)[20] provided test statistics that can be used to test for stationarity of the transition probabilities.

19 Kalbfleisch, J. D. and J. F. Lawless, (1984), Least-Squares Estimation of Transition Probabilities From Aggregate Data, Canadian Journal of Statistics, Vol. 12, No. 3, pp. 169–82.
20 Kelton, W. David, and Christina M.L. Kelton (1984), Hypothesis Tests for Markov Process Models Estimated from Aggregate Frequency Data, Journal of the American Statistical Association, Vol. 79, No. 388, pp. 922–28.

3.3. Gravity model

The banknotes are considered here as a good, so their migration is strictly related to, inter alia, the movement of people (commute to work, business trip, etc.). Thus, the gravity-like properties of cash migration point to the Gravity model as one of the most pervasive empirical models in regional science. The Gravity model resembles Newton's 1687 law of gravity and is widely used by academics and policy advisors[21]. The most commonly applied form of the model in the case of population migration is as follow[22]:

$$(24) \quad F_{ij} = G\frac{P_i^{\alpha}P_j^{\beta}}{D_{ij}^{\gamma}}$$

where F_{ij} represents the scale of migration from the *i*-th to the *j*-th area, P_i, P_j - the population in areas, D_{ij}- the distance between the *i*-th and the *j*-th area, *G*- the proportionality constant dependent on the geography, time dimension, etc.

As you can see, the model assumes existing flows between two regions: origin *i* and destination *j*, which are directly proportional to their size, the gravitational "mass" (e.g. population, GDP, area) and are inversely proportional to the distance between them.

We decided to choose the following independent variables: the GDP of regions as a gravitational mass (because of the transaction denomination 10 zloty), and physical distances between regions. The transition probabilities of the Markov Chain express the attractive force between source and destination regions, so we decided to choose them as a dependent variable.

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21 Ramos R. (2016), Gravity models: A tool for migration analysis, IZA World of Labor 2016:239.
22 E.g. Poot J., Alimi O., Cameron M.P. and D.C. Maré, (2016), The Gravity Model of Migration: The Successful Comeback of an Ageing Superstar in Regional Science, IZA Discussion Paper series, No. 10329, October.

In the case of our analysis, the model specification in the simple log-log version suitable for estimation by the OLS method is as follows:

(25)

$$\ln p_{ij} = \beta_0 + \beta_1 \cdot \ln\left(\mathrm{GDP}_i/\mathrm{GDP}_j\right) + \beta_2 \cdot \ln\left(distance_{ijave}\right) + \beta_3 \cdot \ln\left(distance_{ijmin}\right) + \\ + \beta_4 \cdot border_{ij} + \varepsilon_{ij}$$

where $distance_{ijave}$ means the average distance between the capitals of voivodships included in the regions, $distance_{ijmin}$ denotes the minimum distance between the capitals of voivodships included in the regions, $border_{ij}$- dummy variable equals 1 if the pair of the *i*-th and the *j*-th regions share a contiguous border, $\boldsymbol{\varepsilon}_{ij}$ denotes a random error term. Parameter $\boldsymbol{\beta}_0$ refers to a gravitational constant.

4. Results

4.1. Markov Chain model

The GLS technique described in Section 3 allows to obtain consistent, unbiased and the most effective estimators of transition probabilities p_{ij} of the Markov chain based on macro data presented in Section 2. The results of the estimation are presented in *Table 1*.

Based on the p_{ij} estimation, we can calculate the state distribution $\mathbf{d}_n$ separately for each region and compare it with real proportions of notes in the regions. For this purpose, we used two kinds of goodness-of-fit measures: coefficient of determination R^2 and Theil coefficient *I*. Both of them were assessed in two variants which depend on how the state distributions $\mathbf{d}_n$, n=1,…,N, were estimated (forecasted).

The first case, named as a static, assumes $\mathbf{d}_n$ estimation as a one-step ahead forecast using in (14) the actual value of the lagged $\mathbf{d}_{n-1}$.

Transition matrix P Table 1

	S-E	S-W	S	W	N-W	E-C	N-C
S-E	0.883	0.017	0	0.04	0	0.053	0.006
S-W	0.028	0.957	0	0	0	0.015	0
S	0.007	0.034	0.959	0	0	0	1E-16
W	9E-04	0.004	0.004	0.969	0	0.014	0.008
N-W	0	0	0	0	0.972	0	0.028
E-C	0.008	0.005	0	0	0.012	0.968	0.008
N-C	0.023	0	0.013	0	0	0	0.965

The second case, named as a dynamic, assumes dn estimation as a multi-step forecast using in (14) the previously forecasted values $\mathbf{d}_{n-1}$, for n=3,…,N. State distribution at n=2 is estimated according to static methodology.

The obtained values of two coefficients in two variants are presented in *Table 2* (static) and *3* (dynamic). Besides the two main coefficients, both tables include additional factors strictly related to Theil coefficient I:

- s_p and s_r–sample standard deviations of forecast and real data respectively,
- r- sample correlation between forecast and real value.

The three last columns show elements of the Theil coefficient as an effect of decomposition: bias proportion (I_1), variance proportion (I_2) and the covariance proportion (I_3). It can be noticed that the proportions sum up to 1. The proportions tell us why the forecasts and real data are different. The bias proportion points out the difference between the mean of the theoretical and real value. The second propor-

R^2 and Theil coefficients in *static* version of $\mathbf{d}_n$ calculation

Table 2

	R^2	Theil	s_r	s_p	r	I_1	I_2	I_3
S-E	0.9995	0.0000	0.0207	0.0207	0.9997	0.0021	0.0001	0.9978
S-W	0.9999	0.0000	0.0338	0.0338	0.9999	0.0005	0.0001	0.9995
S	0.9998	0.0000	0.0196	0.0196	0.9999	0.0016	0.0042	0.9942
W	0.9996	0.0001	0.0863	0.0863	0.9998	0.0000	0.0000	1.0000
N-W	0.9993	0.0000	0.0257	0.0256	0.9997	0.0002	0.0280	0.9719
E-C	0.9996	0.0000	0.0550	0.0550	0.9998	0.0002	0.0007	0.9990
N-C	0.9999	0.0000	0.0447	0.0447	0.9999	0.0012	0.0001	0.9987

R^2 and Theil coefficients in *dynamic* version of $\mathbf{d}_n$ calculation

Table 3

	R^2	Theil	s_r	s_p	r	I_1	I_2	I_3
S-E	0.9951	0.0003	0.0207	0.0204	0.9983	0.2431	0.0660	0.6909
S-W	0.9948	0.0004	0.0338	0.0327	0.9986	0.2678	0.1993	0.5329
S	0.9780	0.0022	0.0196	0.0187	0.9913	0.1422	0.1077	0.7502
W	0.9915	0.0016	0.0863	0.0857	0.9958	0.0033	0.0051	0.9917
N-W	0.9005	0.0058	0.0257	0.0244	0.9508	0.0360	0.0263	0.9377
E-C	0.9697	0.0005	0.0550	0.0537	0.9926	0.0625	0.0347	0.9029
N-C	0.9884	0.0008	0.0447	0.0442	0.9943	0.0183	0.0124	0.9693

tion refers to difference between variances. The last one measures the remaining unsystematic forecasting error.

Surprisingly good and very promising results can be seen:

- every region is characterised by R^2 with a value above 0.97 (apart from region N-W with a value closed to 0.9 for dynamic version) and *I* with value closed to 0;
- the values of s_r and s_p are very similar,
- the value of correlation *r* is close to 1,
- the proportion I_3 is the greatest among all proportions of *I*.

The worst fit is observed for the N-W region (the lowest value of R^2 and the highest value of *I* in the dynamic version of the coefficient), which is likely the result of aggregation. Namely, the N-W region comprises two, non-neighbouring voivodships, which can disturb the Markov property.

However, proper levels of coefficients, especially in the *dynamic* version (*Table 3*), prove acceptable goodness-of-fit of the MC model.

It suggests that the first-order Markov Chain can be used to describe the movement of fit notes properly. It is especially important in the studied case of such kind of state aggregation, which gives us some geographical regions with large areas, regions with two and more neighbouring regions and region with two separate area.

Consequently, the obtained results may suggest that the unobserved Markov Chain with states represents small regions (voivodships, powiats or even gminas as a smaller regions of voivodship) and has property of lumpability, i.e. there is the method of state aggregation which gives us the aggregated Markov Process.[23]

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23 In the literature we can meet the definition of strong and weak lumpability - see for example Buchholz P. (1994), Exact and ordinary lumpability in finite Markov chains. J Appl Probab 31(1), pp. 59–75 and subsequent papers.

For the purpose of identification of MC properties, the following eigenvalues λ_i for transition matrix **P** were calculated: λ_1=1, λ_2=0.9691+0.0182*i*, λ_3=0.9691-0.0182*i*, λ_4=0.9497+0.0083*i*, λ_5=0.9497-0.0083*i*, λ_6=0.8744. We can see 3 real and 3 complex eigenvalues. Because of the existence of the unique eigenvalue 1 and other eigenvalues with an absolute value (*modulus*) below 1
($|\lambda 1|$=1, $|\lambda 2|=|\lambda_3|$=0.969,$|\lambda_4|=|\lambda_5|$=C=0.8744), **matrix P is regular**. It is the proof that the Markov Chain describing notes migration is ergodic.

Some elements of **P** matrix equal 0, which means there is no chance of note movement between some regions during one week. A more convenient form for migration analysis comprises a transition matrix after a longer period of time such as *n*=4 (after month) - *Table 4* and *n*=12 (after quarter) - *Table 5*.

Transition matrix for 4 steps (month) P^4 Table 4

	S-E	S-W	S	W	N-W	E-C	N-C
S-E	0.614	0.056	0.001	0.129	0.003	0.173	0.024
S-W	0.087	0.843	3E-05	0.006	0.001	0.062	0.002
S	0.028	0.119	0.846	0.002	4E-05	0.005	3E-04
W	0.005	0.016	0.014	0.883	1E-03	0.053	0.029
N-W	0.003	9E-05	0.002	9E-05	0.894	1E-04	0.1
E-C	0.027	0.018	6E-04	0.002	0.043	0.879	0.03
N-C	0.072	0.004	0.046	0.005	5E-05	0.006	0.867

Transition matrix for 12 steps (quarterly) P^{12} Table 5

	S-E	S-W	S	W	N-W	E-C	N-C
S-E	0.258	0.104	0.009	0.222	0.025	0.32	0.063
S-W	0.145	0.614	0.001	0.04	0.011	0.175	0.015
S	0.07	0.259	0.606	0.015	0.002	0.044	0.004
W	0.022	0.044	0.035	0.691	0.009	0.13	0.071
N-W	0.023	0.003	0.017	0.003	0.715	0.005	0.234
E-C	0.055	0.045	0.006	0.013	0.103	0.695	0.083
N-C	0.125	0.034	0.102	0.033	0.002	0.047	0.656

We can see nonzero elements of such *n*-step transition matrix, which confirms ergodic properties of the Markov Chain. The comparison of the probability $p_{ii}^{(n)}$ that the note will remain in the same state *i* during some period of time is very interesting. Sets of the probabilities for *n*=1,4 and 12 are presented in *Table 6*.

Sample interpretation refers to region E-C with the NBP branch located in Warsaw as one of two sources of the introduction of test notes into circulation. A fit note which was at the beginning at region E-C will be at the same region after 1 quarter with a probability of 0.6947. Or in other words, 69.47% of fit notes introduced in Warsaw at the beginning of the project will be at the same region after 1 quarter.

The properties of MC ergodicity means the existence of unique, final distribution **e** independent of initial states. This distribution can be interpreted as a proportion of fit notes in the regions after a long time.

The n-step transition probabilities P[12] Table 6

$$p_{ii}^{(n)} = P\{X(n) = i/X(0) = i\}$$

$p_{ii}^{(n)}$	S-E	S-W	S	W	N-W	E-C	N-C
n=1 (week)	0.8832	0.9573	0.9591	0.9692	0.9724	0.9675	0.9646
n=4 (month)	0.6139	0.8428	0.8462	0.8826	0.8941	0.8789	0.8665
n=12 (quarter)	0.2578	0.6135	0.6062	0.6908	0.7149	**0.6947**	0.6564

In our case, the time of convergence of distribution $\mathbf{d}_n$ to final distribution **e** equals 209 weeks.[24]

The obtained **e** values together with the distribution of notes between regions estimated by GDP sharing and cash returned to the Bank (RCF) are presented in *Table 7* (for RCF method data from the last month of the project was taken into account). We can see the expected similarity between distributions based on **e** and GDP, which follows from the earlier described method of $k_i(t)$ estimation according to (4). Comparative analysis of RCF's distribution proves the weakness of the approach for distribution estimation based on flow of returned notes to the Bank.

But we should remember that the practical existence of the final distribution **e** requires an unrealistic assumption about the infinite lifetime of notes. However the

24 Convergence time equals the minimum of n for which $|\mathbf{d}_n - \mathbf{e}| < 1E{-}4$.

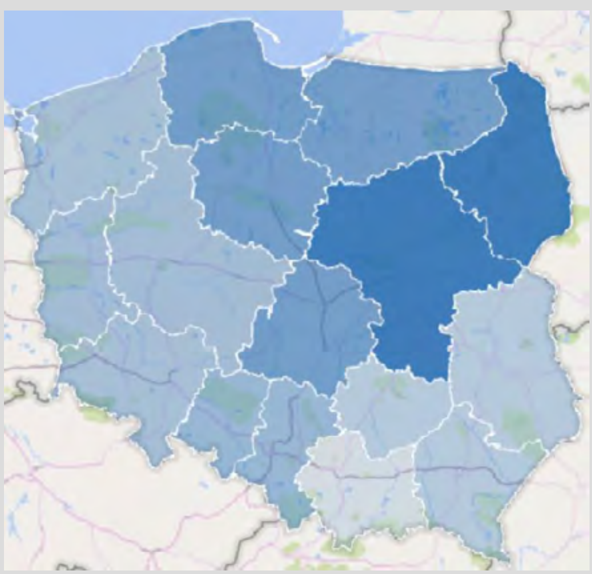
Final state distribution e, sharing of GDP and of Return Cash Flow – RCF among the regions

Table 7

	S-E	S-W	S	W	N-W	E-C	N-C
e	9.28%	13.62%	7.17%	12.15%	11.61%	26.92%	19.25%
GDP	10.06%	14.37%	7.96%	12.10%	12.10%	24.45%	18.96%
RCF	10.36%	8.04%	5.71%	13.94%	12.87%	29.62%	19.45%

Proportion of notes in circulation in regions
(darker colour- higher banknotes saturation)

Figure 4



Fundamental matrix Z Table 8

Z	S-E	S-W	S	W	N-W	E-C	N-C
S-E	6.37	-2.13	-2.91	4.40	-2.88	3.08	-4.93
S-W	1.41	17.15	-4.56	-2.09	-3.72	1.12	-8.30
S	0.04	10.33	18.43	-3.89	-6.41	-5.11	-12.40
W	-2.95	-3.57	-1.42	24.66	-5.86	-3.85	-6.01
N-W	-1.92	-6.37	0.24	-6.46	24.58	-17.26	8.18
E-C	-1.45	-4.80	-2.83	-5.84	2.38	15.28	-1.74
N-C	1.44	-1.44	2.84	-2.06	-7.44	-7.51	15.16

value of **e** gives us an idea of how note location could stabilise across the country. *Figure 4* presents the map of Poland with proportions of notes in circulation marked in the 7 regions considered here.

The Markov Chain as a model of migration allows to estimate two kinds of mean time: first passage and recurrence time defined in Section 3.

For this purpose, we calculated the fundamental matrix **Z** according to the formula (10). The elements of **Z** matrix are presented in *Table 8*.

The Mean First Passage Time for every pair (*i,j*) of regions is included in *Table 9*. *Table 10* presents the second kind of time - Mean Recurrence.

We can see, that the MFPT matrix is asymmetric with non-diagonal elements with values from 36.23 up to 320.7 weeks.

Mean First Passage Time Table 9

	S-E	S-W	S	W	N-W	E-C	N-C
S-E	0.00	141.54	297.68	166.83	236.58	45.32	104.36
S-W	53.42	0.00	320.70	220.25	243.87	52.61	121.88
S	68.20	50.06	0.00	235.03	267.00	75.74	143.16
W	100.45	152.07	276.87	0.00	262.32	71.06	109.98
N-W	89.33	172.68	253.69	256.16	0.00	120.88	36.23
E-C	84.28	161.15	296.56	251.11	191.27	0.00	87.78
N-C	53.10	136.45	217.45	219.93	275.92	84.65	0.00

Mean Recurrence Time τ_i Table 10

S-E	S-W	S	W	N-W	E-C	N-C
10.8	7.34	13.9	8.23	8.62	3.71	5.19

For example, notes migrate faster from N-W to S-E than in the opposite way. Notes located in the N-W region can be expected in the S-E region after 89.33 weeks. But notes located in the S-E region can pass to the N-W region on average in 236.58 weeks.

For some pairs of regions (e.g. N-C and E-C, which have a long border) the movement times in both directions are similar.

The long length of transition time between some regions can be explained in different ways. The first reason is related to the high value of p_{ii}, i.e. the *i*-th region doesn't allow the banknote to leave its location because of its strong attractive force. However, there is a second explanation based on the fact of the use of macro data for estimation. Such a kind of data registers movement of notes by their number, not by individual characteristics. In other words, it is not possible to identify bilateral movement of the same number of notes between regions during a time which is shorter than one week (step) by macro data.

We can notice unexpected short mean recurrence times for every state (expected number of steps to return to state i if MC is started in the same state). According to the methodology of MRT estimation, when the note stays in the same region during one step, then the recurrence time is at the level of 1. Therefore, a short MRT time for each state is caused by a high level of p_{ii}.

4.2. The Gravity model

In our analysis we considered two kinds of Gravity model with 12-step transition variable $p_{ij}^{(12)}$, $i \neq j$ as a dependent variable describing the chance of a state change at 12 steps (3 months):

- Model 1 defined at the level with the following explanatory variables: GDP of origin and destination regions, two kinds of distances between regions (as an average and minimum of distances between capitals of voivodships) and dummy variable for pairs of regions that share a contiguous border;
- Model 2- log-log function (25).

The estimation results of models are presented in *Table 11* (for Model 1) and *Table 12* (for Model 2).

In the case of both models, we see the expected sign of parameters for GDP. The greater the GDP of the origin region and the lower the GDP of the destination region, the lower the scale of note migration. However, in Model 2 (as a log-log version of

Results of Model 1 estimation with dependent variable $p_{ij}^{(12)}, i \neq j$ Table 11

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GDP_i	-0.167142	0.214066	-0.780796	0.4399
GDP_j	0.409465	0.214066	1.912798	0.0635
$Distance_{ijAVE}$	-7.83E-05	0.000177	-0.442657	0.6606
$Distance_{ijMIN}$	0.000180	0.000231	0.777439	0.4418
$BORDER_{ij}$	0.043839	0.028174	1.556032	0.1282

R-squared	0.176357	Mean dependent var	0.065851
Adjusted R-squared	0.087314	S.D. dependent var	0.077525
S.E. of regression	0.074063	Akaike info criterion	-2.256457
Sum squared resid	0.202957	Schwarz criterion	-2.049592
Log likelihood	52.38560	Hannan-Quinn criter	-2.180633
Durbin-Watson stat	2.403492		

Gravity model) the variable of GDP is not significant. It may mean that migration of notes is not influenced mainly by better economic opportunities of destination region.

In the case of both models, the fact of the existence of a border influences the higher transition probabilities between regions, which may be the result of the CIT company network as well as commuting to work in neighbouring regions.

Parameters for distances measured both by average and by minimum lenghts have an unexpected sign (except the average distance in Model 1). In the era of fast passenger connections and the Internet supporting homework, such results should not be surprising.

Results of Model 2 estimation with dependent variable $log\left(p_{ij}^{(12)}\right), i \neq j$

Table 12

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG(GDP_i / GDP_j)	-0.449387	0.418642	-1.073439	0.2900
LOG($Distance_{ijAVE}$)	0.787522	1.054230	0.747011	0.4598
LOG($Distance_{ijMIN}$)	0.563928	0.867249	0.650249	0.5195
$BORDER_{ij}$	1.167449	0.639411	1.825820	0.0760
C	-11.56685	5.095931	-2.269822	0.0291

R-squared	0.112021	Mean dependent var	-3.522294
Adjusted R-squared	0.016023	S.D. dependent var	1.465869
S.E. of regression	1.454077	Akaike info criterion	3.697964
Sum squared resid	78.23060	Schwarz criterion	3.904829
Log likelihood	-72.65724	Hannan-Quinn criter	3.773788
F-statistic	1.166915	Durbin-Watson stat	2.186090
Prob(F-statistic)	0.341134		

However, the **R-square** indicates that both models explain less than 20% of the variation of the dependent variable.

Similar analysis (not reported here) with population sizes as an additional explanatory variables were conducted. The results obtained were almost identical as for GDP: with the expected sign "-" for origin region and "+" for destination region. This means that the greater the size of the origin population and the lower the size of the destination population, the lower the chance of migration.

5. Conclusions

This paper is the first country study on note migration in Poland. Access to the data for the lowest, transactional denomination has given us the possibility to investigate the specificity of note migration.

For this purpose, the Markov Chain model was used. The states of MC represent the geographical location of notes, transition probabilities describe the chance of note movement between regions. Despite state aggregation, which gave us some large regions with two and more neighbouring regions as well as one region consisting of two non-neighbouring voivodships, the determination and Theil coefficients are proof of acceptable goodness-of-fit of the MC model. It seems to be the most important result of our analysis. The Markov Chain, explored here, as a model of note movement offers the opportunity to estimate some factors such as:

1. mean first passage time,
2. mean recurrence time,
3. final state distribution.

Additionally, the values of transaction probabilities of the MC allowed us to analyze the influence of some factors of region such as GDP, population, area and border on the scale of migration.

And finally, the properties of the MC show, that:

1. Movement of fit notes in Poland can be modelled by a non-absorbing Markov Chain. Absorbing states could be used in a situation of fit and unfit notes consideration;
2. Despite seasonal movement of notes (e.g. summer holidays) the time-homogeneous process correctly describes migration of notes;
3. There is a unique, final (stationary) state distribution independent of the starting state (first introduction to the circulation) under assumption about infinite life time of notes.

It is worth noting that the literature offers methods of MC consideration with the population changing over time. Such an approach could be useful in the case of changing assumptions about the same value of note shredding rates in each region–see Kalbfleisch and Lawless (1984).[25]

The final conclusion from the obtained results refers to the possibility of the application of the MC model for investigating note migration between countries in the euro zone. Namely, the Markovian model may be used to describe movement of sample (test) notes with selected denomination from country to country or even between groups of countries. The smallest denomination is preferred because of its liquidity.

A quantitative analysis of note migration should be preceded by data collection. The serial number reading function of sorter machines can help to gather micro data on the current location of test notes. It is advisable to introduce a sample of notes (about 2-3% of the amount of notes with selected denomination in circulation) in at least three countries such as Germany, Spain (or Portugal) and Greece (or one of the Baltic countries).

The method of countries aggregation and consequently definition of the Markov Chain states will be dependent on which countries decide to collect data on the test notes. Set of aggregation criteria, besides geographical location, should also include payment habits of societies.

The results obtained will be able to describe not only the specificity of note migration in the eurozone, but will also support the identification of the scale of cash of circulation in each country.

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Matthias Uhl

Coin migration between Germany and other euro area countries[1]

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Abstract

Euro coins have a common European side and an individual national side. Thanks to coin migration, coins bearing a panoply of national sides are in circulation throughout the euro area. In this paper, we model the mixing of coins circulating in the euro area countries and in particular the extent of coin migration in the euro area. A model calibration suggests that, for the coin denominations €2, €1, 50 cent and 20 cent roughly the same quantity of euro coins migrate from Germany to the rest of the euro area as vice versa. Accordingly, the relatively large

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quantities of coins issued by the Federal Republic of Germany are not materially explained by exports of coins to other euro area countries.

1 Introduction

Euro coins have a common European side and a national side. As a result of coins being taken along by travellers, amongst other reasons, national coin holdings in the euro area consist of coins with a mixture of national sides. One reason for studying coin migration is its potential implications for the distribution of coin revenues between the euro area countries. Coin revenue accrues directly to the Member State. National coin revenues in the euro area are directly linked to the size of the demand for coins among national coin-issuing authorities. If more coins migrate from one euro area country to the rest of the euro area than vice versa, this euro area country is, to a degree, also meeting coin demand in other euro area countries. In this sense, a Member State reporting net outflows of euro coins can obtain more coin revenues than other Member States.[2]

Germany has issued relatively large quantities of euro coins, raising the question as to whether the German coin issuance is primarily driven by domestic demand or net outflows to other euro area countries. In the latter case, Germany would be able to collect larger coin revenues by exporting coins to other euro area countries. At end-2017, a total value of €28 billion worth of euro coins were in circulation, of which the Bundesbank brought into circulation €8.4 billion net. The Bundesbank thus brought a net amount of 29.9% of all circulating euro coins into circulation, whereas it accounted only for 25.6% of the European Central Bank's fully paid-up capital. The Bundesbank therefore brought more euro coins into circulation than would have been expected going by its capital key, thus enabling the Federal Republic of Germany to reap that much greater seigniorage over the years since the introduction of the euro as a physical currency. The size of the capital key share is

2 Small excerpts of this paper have been published in Deutsche Bundesbank (2019).

based on population size and gross domestic product (GDP), i.e. variables which should very well be able to contribute to explaining domestic coin demand. However, there are additional conceivable determinants of national demand for coins. The extent to which cash is used to make payments, or national particularities regarding the usage of certain coin denominations, are likewise examples of factors which could impact on the demand for coins in euro area countries. Comparing the share of total cumulative coin issuance with the capital key therefore does not permit us to draw any direct inferences about any possible net migration of coins in the euro area. The purpose of the present paper is to examine coin migration between Germany and the other euro area countries using a calibrated model of the mixture of national coin stocks.

We will begin by developing a model which describes the mixture of national transaction balances with coins bearing a variety of different national sides. A fundamental distinction can be made between euro coins held for transaction purposes and coin hoards. For the purposes of this paper, a coin hoard shall denote coins which are saved or collected or which are permanently lost (Deutsche Bundesbank, 2015). In the model presented below, coins transition between regions as well as between transaction balances and coin hoards. The model parameters are then calibrated on the basis of the available data on the euro coin circulation and the mixture of transaction balances as well as of assumptions regarding the evolution of transaction balances. The estimates conducted in this way indicate that roughly the same amount of coins travel from Germany to the rest of the euro area as vice versa. Accordingly, it is not coin exports but instead primarily national determinants which shape the issuance of coins by the Federal Republic of Germany. As discussed below, a set of assumptions is necessary when choosing the model parameters, but the results are robust to deviations from the baseline assumptions.

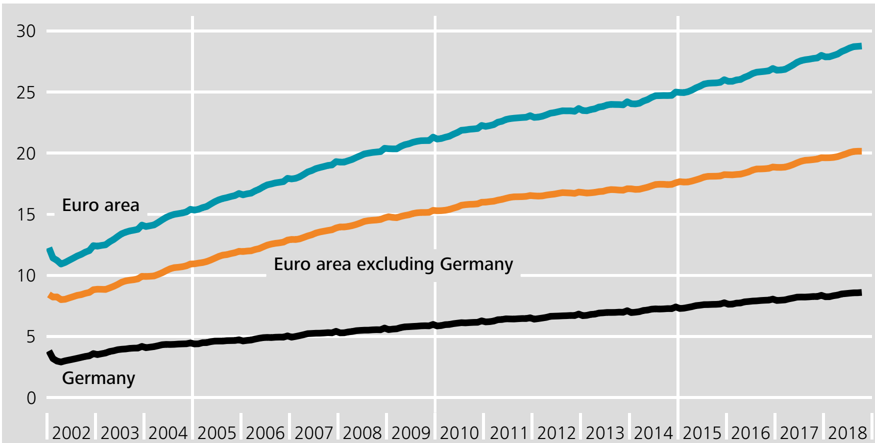
Overall, the literature analysing coin demand is scarce. Seitz et al. (2012) also propose a model for coin migration in the euro area. A common idea in our work and in Seitz et al. (2012) is that coins transition between coin demand components at fixed transition rates. However, this paper expands on the approach applied by Seitz et al. (2012) by developing a substantially extended model of coin migration and by using a new dataset on the mixing of euro coins. One important contribution is that this paper introduces a distinction between three components of coin demand – domestic transaction balances, domestic hoards and foreign demand – which should yield a fuller picture of the determinants of demand for coins. In order to calibrate their model, Seitz et al. (2012) set net coin migration at zero in a baseline period. For the first time, we are able to use a dataset describing the composition of national coin stocks in Germany and the euro area excluding Germany, thus enabling us to estimate coin in- and outflows from the data. In addition, we are able to cover the €2, €1, 50 cent and 20 cent coin denominations, while Seitz et al. (2012) cover only the case of the €1 coin. Taken together, this paper provides the first comprehensive estimates on the importance of coin outflows for the German coin issuance.

Altmann and Bartzsch (2014) and Deutsche Bundesbank (2015) study the holding of euro coins for transaction purposes in Germany using what is called the seasonal method. According to the results, transaction balances of euro coins in Germany amounted to €2.3 billion in 2011. That corresponded to 36% of all euro coins in circulation in Germany at that particular point in time. Goldin (1985) studies the lifetime and transactions balances of Israeli coins by looking at the dates stamped on each coin. However, knowledge of transaction balances does not translate directly to information on coin migration. The remaining coins could either be being hoarded or have migrated abroad.

The remainder of the paper is structured as follows. Section 2 describes the circulation of euro coins and sets out the dataset used for the subsequent analyses. Section 3 contains the model for coin migration. In Section 4, plausible parameters for this model are set, from which empirical implications are derived. Section 5 summarises and concludes.

Circulation of euro coins in the euro area Figure 1

€ billion



Sources: Deutsche Bundesbank and European Central Bank.

2 Euro coin circulation

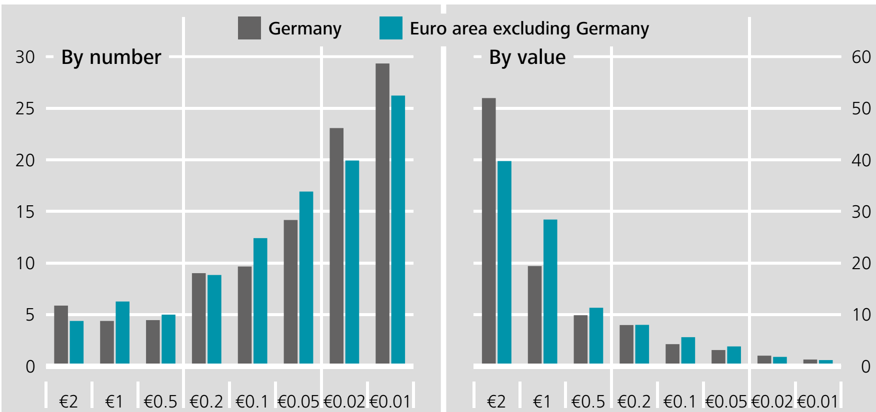
Figure 1 shows the development of the euro coin circulation over time. The cumulative net issuance of euro coins, defined as the cumulated difference between outpayments and inpayments, has risen evenly in both Germany and the euro area excluding Germany. According to the results presented in Deutsche Bundesbank (2015), changes in domestic transaction balances cannot explain the increase in German coin issuance. One purpose of this paper is to investigate the relative importance of coin hoarding and coin migration for the development of the national coin issuances using a calibrated coin mixture model.

Figure 2 shows the composition of euro coin circulation by denomination in Germany and the euro area excluding Germany. What is striking is that German euro coin circulation is much more heavily concentrated on the €2 coin than is the case in the euro area excluding Germany. The relatively large circulation of German €2

Share of each denomination in euro coins in circulation as at end-2017

Figure 2

%



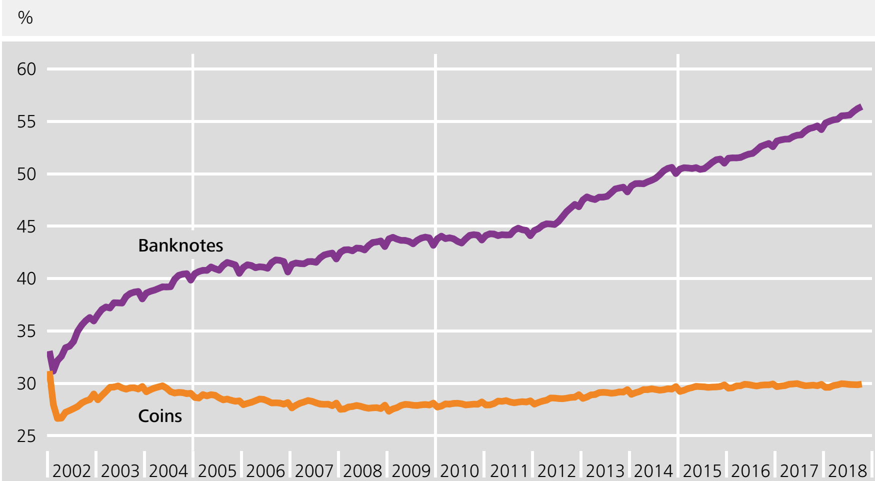
Sources: Deutsche Bundesbank and European Central Bank.

coins is a key determinant of the volume of German coins in circulation overall and explains at least in part why Germany's share of the total amount of euro coins in circulation exceeds the Deutsche Bundesbank's capital share. It is possible that €2 coins are being more widely used in Germany as change or for collection or hoarding purposes than in other euro area countries. This would push national determinants for the high demand for coins in Germany to the foreground.

It is well known that a considerable quantity of euro banknotes has migrated from Germany to other euro area countries and to non-euro area foreign countries (Bartzsch et al., 2011a, Bartzsch et al., 2011b, Bartzsch and Uhl, 2017; Deutsche Bundesbank, 2018a). There has been a clear growth in the Deutsche Bundesbank's share of cumulative net issuance of euro banknotes (*Figure 3*), rising from around 35% towards the end of 2002 to already as much as around 55% in December 2017. On the other hand, German euro coins' share of cumu-

Deutsche Bundesbank's share in cumulative net issuance

Figure 3



Sources: Deutsche Bundesbank and European Central Bank.

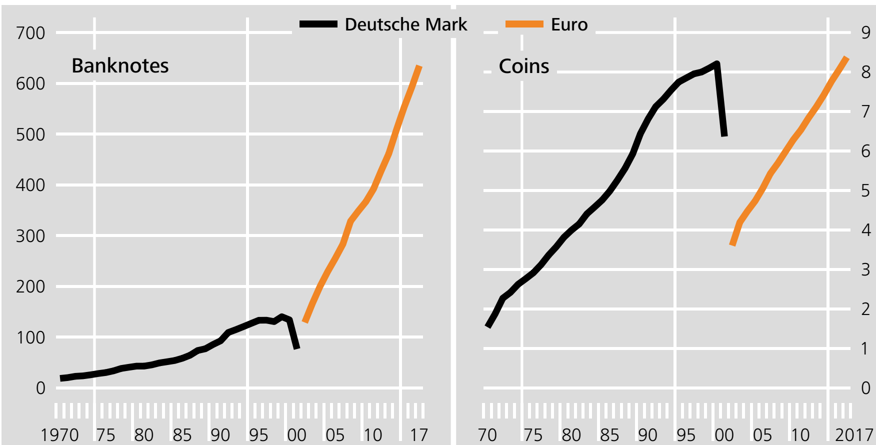
lative net coin issuance has remained fairly stable at around 30% for many years. Where domestic demand trends are identical in two countries in a monetary union, cash migration is reflected in a rising share for the country sending cash and a falling share for the country receiving cash. Whereas the Bundesbank's share in the case of banknotes actually is rising, Germany's share in the case of coins is relatively constant. This would be consistent with net outflows of coins from Germany to the rest of the euro area only if the domestic demand in the rest of the euro area were to rise more quickly than in Germany. There is no empirical evidence of this, however.

Evidence for the significance of foreign demand for the Bundesbank's cash issuance may also be inferred from *Figure 4*. This figure shows long time series for the trend patterns of German banknote and coin circulation – for Deutsche Mark cash up to and including 2001 and euro cash from 2002 onwards. Cumulative

Currency in circulation in Germany

Figure 4

€ billion



Source: Deutsche Bundesbank.

net issuance of banknotes apparently seems to rise much more quickly following the introduction of euro banknotes and coins than previously. This marked break in banknote issuance is probably attributable to the fact that euro banknotes have been migrating from Germany to other countries at a greater rate than was the case for DM banknotes in the past (Deutsche Bundesbank, 2009). Such a marked break caused by the introduction of the euro in physical form, as would have been fundamentally expected given a rise in the importance of euro coin migration relative to DM coin migration, is lacking in the figure for coins, however.

Based on the foregoing, we form the hypothesis that coin outflows from Germany to other euro area countries and coin inflows to Germany are balanced. The objective of this paper is to review this hypothesis using a coin mixture model. Empirically plausible parameters for the model are to be set using available data on coin mixture. For random samples of €1 and €2 and 20 and 50 cent coins taken

Share of German euro coins in Germany and the rest of the euro area Table 1

	Germany	Euro area excluding Germany
€2 coin	61%	20%
€1 coin	49%	16%
50 cent coin	57%	15%
20 cent coin	62%	13%

Sources: Deutsche Bundesbank and Mint Directors Working Group.
Notes: Data from 2016. The share of German euro coins in the rest of the euro area is calculated as an unweighted average of the shares in 15 euro area countries.

from cash lodgements in its branches, the Bundesbank establishes composition by national reverse sides on an annual basis. These cash lodgements result from the use of cash as a means of payment and thus originate from coin stocks held for transaction purposes. Consequently, this exercise tells us the country of manufacture for holdings of coins as transaction balances. Comparable surveys are also conducted in the other euro area countries. *Table 1* provides an overview of the results. These show that the share of German euro coins for the above denominations ranged from 49% to 62% in Germany and between 13% and 20% in the rest of the euro area. For the first time, this dataset can be used to study coin migration in a scientific paper.

3 Coin migration model

3.1 Coin shares in case of positive net issuances

We will develop a model for the mixing of coins held in transaction balances in two countries, called D for domestic and A for abroad, below. The model shares several ideas with the model developed in Seitz et al. (2012), but, as argued above, expands it in several important dimensions. In the application presented in Section 4, the domestic country will be Germany and the other region will be the euro area excluding Germany. Let $T_{D,t}$ denote the number of coins held in transaction balances in country D at time t and $T_{A,t}$ the number of coins in active circulation in country A. Euro coins can be assigned by national sides to their countries of first issue.[3] However, thanks to coin migration, a given coin may not necessarily be in the country of first issue anymore. Let thus $T_{DA,t}$ denote the number of coins with the national side of country D located in transaction balances in country A at time t. $T_{DD,t}$, $T_{AA,t}$ and $T_{AD,t}$ are defined in similar fashion.

To begin with, we fix the time path of the transaction balances in country D, $T_{D,t}$, and in country A, $T_{A,t}$, by assuming fixed exogenous growth rates g_D and g_A. Thus, the following equations describe the size of the transaction balances in the two regions at time t.

(1) $T_{D,t}=(1+g_D)^t T_{D,0}$, $t=0,1,\ldots$

(2) $T_{A,t}=(1+g_A)^t T_{A,0}$, $t=0,1,\ldots$

Equations (1) and (2) imply, for $g_D \neq 0$ or $g_A \neq 0$, exponential growth in domestic transaction balances. This assumption is fundamentally plausible if we look at domestic transaction balances as a function of (nominal) income, for which sometimes exponential growth is assumed. For $g_D=g_A=0$ a relevant special case arises, where domestic transaction balances are constant. We are not aware of any theoretical model for the determinants or size of the transaction balance of euro coins. Our paper does not attempt to close this gap, but focuses instead on describing

3 We make the assumption that newly issued euro coins bear the national side of the issuer. However, where cross-border transports of euro coins between coin-issuing authorities occur, it would no longer be possible to accurately assign these coins to their country of origin. For the coin denominations analysed below, there have been no coin shipments between the Deutsche Bundesbank and coin-issuing authorities in other euro area countries. This means that the attribution in this paper of euro coins by national sides to Germany and to the euro area excluding Germany is reliable.

coin mixture, assuming an exogenous path for the size of the transaction balances. There are two conceivable channels of coin migration: coins being taken along by travellers and coin transports effected by professional cash handlers. In both cases, a coin is removed from active domestic circulation and transported abroad. As in Seitz et al. (2012) our model allows coins to migrate between the two regions at fixed rates. Let α_{DA} denote the share of coins which migrate from transaction balances in country D to country A in each period. Likewise, α_{AD} is the share of coins which migrate from active circulation in country A to country D in each period.[4] Then, in period t, $\alpha_{DA}T_{D,t-1}$ coins migrate from country D to country A, of which $\alpha_{DA}T_{DD,t-1}$ bear the national side of country D. Likewise, $\alpha_{AD}T_{A,t-1}$ coins migrate from country A to country D, of which $\alpha_{AD}T_{AA,t-1}$ coins bear the national side of country A.

Overall, coin hoardings – coins which are saved or collected or which are permanently lost – are likely an important component of coin demand (Deutsche Bundesbank, 2015). One contribution of our paper is that coins are allowed to disappear from active circulation into coin hoards.[5] Coins migrate from transaction balances to hoards, for instance, if they are lost or if consumers remove coins from their wallets and put them into some sort of collection receptacle. We assume that each period, a certain share of coins α_D is withdrawn from active circulation in country D and a share of coins α_A is withdrawn from active circulation in country A. Thus, $\alpha_D T_{D,t-1}$ coins disappear from active circulation in country D at time t, of which

4 The discussion paper by Seitz et al. (2009) interprets the coin mixing process as a Markov chain. In this view, a single coin has a probability α_{DA} to switch from region D to region A within a year and a probability α_{AD} to move from region A to region D. Due to the law of large numbers, this implies that a total of $\alpha_{DA}T_{D,t-1}$ coins migrate from region D to region A at time t and $\alpha_{AD}T_{A,t-1}$ coins move from region A to region D at time t.

5 Coins in circulation outside the euro area are not explicitly modelled. In the literature, the assumption that coin stocks outside the euro area are insignificant is regarded as uncontroversial (European Central Bank, 2017). Coins in circulation outside the euro area could be notionally assigned to domestic hoards and thus be captured indirectly. The analysis presented here hinges on the assumption that both hoarded coins and coins circulating outside the euro area have disappeared completely from active domestic circulation.

$\alpha_D T_{DD,t-1}$ bear the national side of country D. $\alpha_A T_{A,t-1}$ coins disappear from active circulation in country A at time t, of which $\alpha_A T_{AA,t-1}$ bear the national side of country A. We also allow for the issuance of new coins. Let $\Delta N_{D,t}$ denote the net issuance of coins in country D at time t and $\Delta N_{A,t}$ the net issuance of country A.

We assume that both net issuances are positive, $\Delta N_{D,t}>0$ and $\Delta N_{A,t}>0$. According to *Figure 1*, the net issuance of Germany and the euro area excluding Germany has typically been positive. Hence, the assumption that both net issuances are positive is appropriate in applications studying the development of the coin shares in Germany and the euro area excluding Germany. By assumption, new issuances of coins bear the national side of the issuing country. New coins are issued to satisfy the additional demand for transaction purposes, $g_D T_{D,t-1}$ and $g_A T_{A,t-1}$, and to replace coins that have disappeared into hoardings, $\alpha_D T_{D,t-1}$ and $\alpha_A T_{A,t-1}$. In addition, from the perspective of country D, $\alpha_{DA} T_{D,t-1} - \alpha_{AD} T_{A,t-1}$ coins have migrated to country A in net terms and have to be replaced by new coins. Thus, the following equations apply.

(3) $\Delta N_{D,t}=(g_D+\alpha_D+\alpha_{DA})T_{D,t-1}-\alpha_{AD}T_{A,t-1}$

(4) $\Delta N_{A,t}=(g_A+\alpha_A+\alpha_{AD})T_{A,t-1}-\alpha_{DA}T_{D,t-1}$

New issuance $\Delta N_{D,t}$ and $\Delta N_{A,t}$ offsets the difference between desired transaction balances $(1+g_D)T_{D,t-1}$ and $(1+g_A)T_{A,t-1}$ and coins actually existing in both regions following hoarding and migration, $(1-\alpha_D-\alpha_{DA})T_{D,t-1}+\alpha_{AD}T_{A,t-1}$ and $(1-\alpha_A-\alpha_{AD})T_{A,t-1}+\alpha_{DA}T_{D,t-1}$.

We are now in the position to characterise the development of the composition of transaction balances over time. Let the following apply to the share of coins bearing the national side of country D in transaction balances in country A:

$$\tau_{DA,t} = \frac{T_{DA,t}}{T_{A,t}};\ t = 0,1,\dots$$

$\tau_{DD,t}$, $\tau_{AA,t}$ and $\tau_{AD,t}$ are defined accordingly. Apparently, $1=\tau_{DD,t}+\tau_{AD,t}$ and $1=\tau_{DA,t}+\tau_{AA,t}$. As argued above, the number of national coins held in national transaction balances are characterised by

(5) $T_{DD,t}=(1-\alpha_D-\alpha_{DA})T_{DD,t-1}+\alpha_{AD}T_{DA,t-1}+\Delta N_{D,t}$

(6) $T_{AA,t}=(1-\alpha_A-\alpha_{AD})T_{AA,t-1}+\alpha_{DA}T_{AD,t-1}+\Delta N_{A,t}$

To summarise the above discussion, $\alpha_D T_{DD,t-1}$ and $\alpha_A T_{AA,t-1}$ coins bearing the national side disappear from active circulation into coin hoards. $\alpha_{DA}T_{DD,t-1}$ coins bearing the national side of country D have migrated abroad, while $\alpha_{AD}T_{DA,t-1}$ coins bearing the national side of country D have returned from country A. Likewise, $\alpha_{AD}T_{AA,t-1}$ coins bearing the national side of country A have migrated to country D and $\alpha_{DA}T_{AD,t-1}$ coins have returned from country D to country A. $\Delta N_{D,t}$ and $\Delta N_{A,t}$ reflect the issuance of new coins. After scaling equation (5) by $T_{D,t}$ and equation (6) by $T_{A,t}$, we obtain the following difference equations for the evolution of the coin shares $\tau_{DD,t}$ and $\tau_{AA,t}$.

(7) $(1+g_D)\tau_{DD,t}=g_D+\alpha_D+\alpha_{DA}+(1-\alpha_D-\alpha_{DA})\tau_{DD,t-1}-\alpha_{AD}\eta_{t-1}\tau_{AA,t-1}$

(8) $(1+g_A)\tau_{AA,t}=g_A+\alpha_A+\alpha_{AD}+(1-\alpha_A-\alpha_{AD})\tau_{AA,t-1}-\alpha_{DA}\eta_{t-1}^{-1}\tau_{DD,t-1}$

$\eta_{t-1}=T_{A,t-1}/T_{D,t-1}$ denotes the ratio between the two sets of coins in domestic circulation at time t-1.

The development of the coin shares $\tau_t=(\tau_{DD,t}, \tau_{AA,t})'$ is thus described by a linear difference equation $\tau_t=b+A_{t-1}\tau_{t-1}$ with some starting value τ_0. In case the national coin issuances are both positive, $\Delta N_{D,t}>0$ and $\Delta N_{A,t}>0$, the elements of this equation are defined as follows.

$$b=\begin{pmatrix}1+g_D & 0\\ 0 & 1+g_A\end{pmatrix}^{-1}\begin{pmatrix}g_D+\alpha_D+\alpha_{DA}\\ g_A+\alpha_A+\alpha_{AD}\end{pmatrix}$$

$$A_{t-1}=\begin{pmatrix}1+g_D & 0\\ 0 & 1+g_A\end{pmatrix}^{-1}\begin{pmatrix}1-\alpha_D-\alpha_{DA} & -\alpha_{AD}\eta_{t-1}\\ -\alpha_{DA}\eta_{t-1}^{-1} & 1-\alpha_A-\alpha_{AD}\end{pmatrix}$$

To ensure that the difference equation is well behaved, we will apply some parameter restrictions. First, we assume $\alpha_D \geq 0$, $\alpha_{DA} > 0$, $\alpha_A \geq 0$ and $\alpha_{AD} > 0$. The growth rate of domestic transaction balances shall be restricted to $-1 < g_D < 1$, which should cover empirically realistic growth rates. We also require that $1-\alpha_D-\alpha_{DA} > 0$ and $1-\alpha_A-\alpha_{AD} > 0$ to ensure that, over a given period, the number of coins that can migrate from transaction balances to hoards or abroad is smaller than the quantity of coins contained in transaction balances themselves. The assumptions $\Delta N_{D,t} > 0$ and $\Delta N_{A,t} > 0$ require that $(g_D+\alpha_D+\alpha_{DA}) > \alpha_{AD}\eta_{t-1}$ and $(g_A+\alpha_A+\alpha_{AD}) > \alpha_{DA}\eta_{t-1}^{-1}$, respectively. These conditions imply, among other things, that $0 \leq \tau_{DD,t} \leq 1$ and $0 \leq \tau_{AA,t} \leq 1$ as long as $0 \leq \tau_{DD,t-1} \leq 1$ and $0 \leq \tau_{AA,t-1} \leq 1$. If $g_D = g_A$, then η is constant and the linear difference equation $\tau_t = b + A\tau_{t-1}$ continues to hold for all t.[6] τ_t will then converge towards $(I-A)^{-1}b$, where I is the two-dimensional identity matrix.

3.2 Coin demand components

The assumptions made in the previous sections characterise the mixture of coins held in transaction balances, but also imply equations for the development of the overall cumulative net coin issuance and its components. The cumulative net coin issuance of a region D (A) in year t, $N_{D,t}$ ($N_{A,t}$), can be decomposed into the domestic transaction balance $T_{D,t}$ ($T_{A,t}$), domestic hoarding $H_{D,t}$ ($H_{A,t}$) and circulating coins abroad $A_{D,t}$ ($A_{A,t}$).

$$N_{D,t} = T_{D,t} + H_{D,t} + A_{D,t};\ t = 0, 1, \dots$$
$$N_{A,t} = T_{A,t} + H_{A,t} + A_{A,t};\ t = 0, 1, \dots$$

According to Equations (1) and (2), domestic transaction balances are given by $T_{D,t} = (1+g_D)^t T_{D,0}$ and $T_{A,t} = (1+g_A)^t T_{A,0}$. α_D and α_A denote the share of domestic transaction balances hoarded annually. Then, the development of domestic hoarding is described by the difference equations shown below.

6 If $g_D \neq g_A$, either the domestic net issuance $\Delta N_{D,t}$ or the foreign net issuance $\Delta N_{A,t}$ will eventually turn negative. The time indices have been dropped to reflect that the parameters are constant.

$$H_{D,t}=H_{D,t-1}+\alpha_D T_{D,t-1};\ t=1,\ldots$$
$$H_{A,t}=H_{A,t-1}+\alpha_A T_{A,t-1};\ t=1,\ldots$$

Defining

$$c_{D,t}=\begin{cases} t, g_D=0 \\ \frac{(1+g_D)^t-1}{g_D}, g_D\neq 0 \end{cases}$$

and

$$c_{A,t}=\begin{cases} t, g_A=0 \\ \frac{(1+g_A)^t-1}{g_A}, g_A\neq 0 \end{cases}$$

and assuming $H_{D,0}=H_{A,0}=0$, the solutions to these difference equations are $H_{D,t}=c_{D,t}\alpha_D T_{D,0}$ and $H_{A,t}=c_{A,t}\alpha_A T_{A,0}$.

α_{DA} and α_{AD} demonstrate the share of coins from the domestic transaction balances of country D and country A which migrate annually to, respectively, country A and country D. Thus, $\Delta A_{D,t}=\alpha_{DA}T_{D,t-1}-\alpha_{AD}T_{A,t-1}$ and $\Delta A_{A,t}=\alpha_{AD}T_{A,t-1}-\alpha_{DA}T_{D,t-1}$ represent coin net migration within period t. Taking the sums across periods, the difference equations below describe the development of foreign demand $A_{D,t}$ and $A_{A,t}$.

$$A_{D,t}=A_{D,t-1}+\alpha_{DA}T_{D,t-1}-\alpha_{AD}T_{A,t-1};\ t=1,\ldots$$
$$A_{A,t}=A_{A,t-1}+\alpha_{AD}T_{A,t-1}-\alpha_{DA}T_{D,t-1};\ t=1,\ldots$$

Assuming $A_{D,0}=A_{A,0}=0$, the solutions to these difference equations are $A_{D,t}=c_{D,t}\alpha_{DA}T_{D,0}-c_{A,t}\alpha_{AD}T_{A,0}$ and $A_{A,t}=-A_{D,t}$.

This distinction of domestic transaction balances, domestic hoarding and foreign demand is common in the literature analysing cash demand (see, e.g., Deutsche Bundesbank, 2018a). Domestic transaction balances and domestic hoarding reflect domestic demand and are thus positive numbers. For regions within a monetary union, foreign demand can turn negative, however. If $A_{D,t}>0$, more coins have migrated from region D to region A than vice versa and the cumulative net issuance, $N_{D,t}$, exceeds domestic demand for coins, $T_{D,t}+H_{D,t}$. In the opposite case, $A_{D,t}<0$, region D is a net receiver of coins and the cumulative net issuance, $N_{D,t}$, is smaller than domestic demand for coins, $T_{D,t}+H_{D,t}$. Thus, domestic demand for coins is partially satisfied by coins from region A. The main objective of the paper is to estimate $A_{D,t}$ and $A_{A,t}$, as these variables summarise coin net flows between the two regions of a monetary union.

4 Model implications with pre-set parameters

The model presented in the last section describes the time path of coin demand components and the shares of each national side in transaction balances. We can study the empirical implications by setting the starting values as well as the model parameters, with the €2 and €1 and 50 and 20 cent denominations each being modelled separately. We will look at two geographical units below: Germany and the euro area excluding Germany.

The discussion from the previous section implies the following two equations for the development of the cumulative net issuance

$$N_{D,t}=N_{D,0}+(g_D+\alpha_D+\alpha_{DA})c_{D,t}T_{D,0}-\alpha_{AD}c_{A,t}T_{A,0}$$
$$N_{A,t}=N_{A,0}+(g_A+\alpha_A+\alpha_{AD})c_{A,t}T_{A,0}-\alpha_{DA}c_{D,t}T_{D,0}$$

and the following equation for the coin shares at time t

$$\tau_t=(I+A_{t-1}+\ldots+A_{t-1}\cdot\ldots\cdot A_1)b+A_{t-1}\cdot\ldots\cdot A_0\tau_0$$

with b and A_i, i=0,…,t-1 defined as in Section 3.1. Apparently, the model yields four equations, but has six unknown parameters (g_D, α_D, α_{DA}, g_A, α_A, α_{AD}) and unknown starting values ($T_{D,0}$, $T_{A,0}$). The general strategy applied in the following will be to fix the growth rates of domestic transaction balances g_D and g_A and the unknown

Model parametrisation Table 2

	€2 coin	€1 coin	50 cent coin	20 cent coin
t	14	14	14	14
$N_{D,0}$	832	921	897	1352
$N_{A,0}$	1727	2762	2860	3797
$N_{D,t}$	2082	1590	1599	3213
$N_{A,t}$	3733	5388	4302	7565
$T_{D,0}$	832	921	897	1352
$T_{A,0}$	1727	2762	2860	3797
$\tau_{DD,0}$	1	1	1	1
$\tau_{AA,0}$	1	1	1	1
$\tau_{DD,t}$	0.61	0.49	0.57	0.62
$\tau_{AA,t}$	0.80	0.87	0.87	0.88
g_D	0	0	0	0
g_A	0	0	0	0
α_D	0.117	0.065	0.067	0.119
α_{DA}	0.094	0.080	0.060	0.060
α_A	0.078	0.063	0.032	0.064
α_{AD}	0.050	0.031	0.022	0.029

Source: Deutsche Bundesbank, European Central Bank, Mint Directors Working Group and own calculations.
Note: All coin demand data in million pieces.

starting values. A numerical procedure is then used to determine α_D, α_A, α_{DA} and α_{AD} such that the implied values for $N_{D,t}$, $N_{A,t}$, $\tau_{DD,t}$ and $\tau_{AA,t}$ correspond to their empirically observed values.[7] *Table 2* shows an overview of the preferred parametrisation. All estimates conducted in this paper depend on the assumptions made when setting up the model as well as while parameterising it and should thus be interpreted with care. To reflect this caveat, we implement a set of robustness exercises.

The model developed in the previous section describes the path of coin demand components as a function of the holding of transaction balances; assumptions regarding the time path of transaction balances therefore play a central role. Merely defining the growth rates g_D and g_A already yields plausible values for the further model parameters. In this paper, it is assumed that the holdings of euro coins for transaction purposes remain constant; therefore, $g_D=g_A=0$.[8] While consumers acquire banknotes from automated teller machines or bank tellers and thus can shape their transaction balances of banknotes by deciding how much to withdraw, coin holdings in wallets are created by receiving change. Consumers therefore have comparatively less scope for manipulating their euro coin holdings for transaction purposes. Seen from this perspective, coin holdings for transaction purposes are a by-product of the use of cash as a medium of payment and are less the outcome of conscious decisions concerning the size of transaction balances held. This underlies the assumption that holdings of euro coins for transaction purposes are

7 The system of equations is solved using the multivariate Newton procedure for solving non-linear equation systems (Judd, 1998). Owing to numerical studies, the existence of a unique solution is suspected, but no formal derivation of this statement exists. The robustness of the numerical results is corroborated by the fact that different starting values for the numerical procedure lead to identical conclusions. Comparable results are also produced if the parameter values are determined in a non-approximative fashion using the limits of $\tau_{DD,t}$ and $\tau_{AA,t}$.

8 The crucial assumption underlying the model parameter settings rests in the choice of $g_D=g_A=0$ for the growth rates of domestic transaction balances. We want to investigate the consequences of deviation from this assumption. To this end, we calculate the volume of German euro coins circulating abroad for different assumptions of the growth rates g_D and g_A of domestic transaction balances. German euro coins in circulation abroad still end up being relatively moderate in amount even under extreme assumptions for growth rates g_D and g_A.

constant. Estimates regarding holdings of euro banknotes for transaction purposes in Germany are available as from the year 2008; over the observed estimation horizon, holdings of euro banknotes for transaction purposes are constant (Bartzsch and Uhl, 2017; Deutsche Bundesbank, 2018a). This is consistent with the assumption that transaction balances of euro coins are likewise constant. According to a Deutsche Bundesbank survey of the public, at the end of 2002 respondents in Germany held, on average, around 16 coins per person in their wallets with a total value of €5.62 (Deutsche Bundesbank, 2003). According to the results of the Deutsche Bundesbank's payment behaviour study, in 2008 respondents were carrying an average value of €6.70 worth of euro coins on their person; in 2011, the figure was €5.90; in 2014, €5.73; and in 2017, €6.29 (Deutsche Bundesbank, 2018b). This means that each German household carries, on average, somewhere around €6 worth of coins in their wallets. These data likewise indicate constant holdings of euro coins for transaction purposes in Germany.

We will choose the end of 2002 as the starting point of our analysis. At this point in time, one-off effects on coins in circulation caused by the introduction of euro cash had already dissipated to a large extent (see *Figure 1*). For small values of the parameters α_D, α_{DA}, α_A and α_{AD}, migration and hoarding during the early stages should be negligible, which means it should be possible to set the domestic transaction balances τ_D and τ_A via coins in circulation $N_{D,0}$ and $N_{A,0}$ at the end of 2002.[9] For the starting values $\tau_{DD,0}$ and $\tau_{AA,0}$, 1 is chosen, which means that the initial supply was effected using domestic coins.[10]

9 The euro cash changeover could have been associated with special demand for coins for hoarding purposes. For example, consumers in the euro area might have shown an increased interest in collecting the new coins. These special effects can be incorporated into the analysis by adjusting the initial size of the domestic transaction balances. Varying the initial size of the transaction balances has little impact on the estimates for net coin migration.

10 In an investigation of the robustness of the results, $T_{D,0}$, $T_{A,0}$, $\tau_{DD,0}$ and $\tau_{AA,0}$ are calculated under the assumption that the usual annual extent of hoarding and migration had already taken place by the end of 2002. The values shown in *Table 2* for α_D, α_{DA}, α_A and α_{AD} are used for this adjustment. This does not make any meaningful changes to the results of this study.

Data on shares of German coins in transaction balances are available for Germany and 15 other euro area countries for the year 2016. $\tau_{DD,t}$ and $\tau_{AA,t}$ are determined for this period, with the share of foreign euro coins in foreign transaction balances, $\tau_{AA,t}$, being calculated as the weighted mean of data for individual euro area countries.[11] The selected weights derive from the respective size of transaction balances. t consequently takes on the value of 14 years. Cumulative net issuance $N_{D,t}$ and $N_{A,t}$ at the end of 2016 is likewise shown in *Table 2*. Seitz et al. (2012) only use information on the share of German €1 coins in Germany for the model calibration. Compared to their work, we are able to cover a wider range of coin denominations and have information on the share of German coins in Germany and the euro area excluding Germany. The latter allows us to freely estimate coin flows between Germany and the other euro area countries, while Seitz et al. (2012) make the assumption that coin flows are balanced.

With the exception of the €1 coin, the hoarding parameters calculated for Germany, α_D, are much larger than the hoarding parameters calculated for the euro area excluding Germany, α_A. This suggests that coin demand in Germany is driven by hoarding to a larger extent than coin demand in other parts of the euro area. As can be inferred from *Table 2*, the migration parameters α_{DA} exceed the migration parameters α_{AD}. This is a plausible result as the euro area excluding Germany is larger than Germany, making it less probable that a coin from this region ends up in Germany.

Once the model parameters have been set, the model equations can be simulated up to the current end of the data, i.e. the year 2016. This results in estimates for coins in circulation $N_{D,t}$ and $N_{A,t}$, the coin demand components $T_{D,t}$ and $T_{A,t}$, $H_{D,t}$ and $H_{A,t}$ as well as $A_{D,t}$ and $A_{A,t}$. The results are shown in *Table 3*. In terms of value, esti-

11 For the denominations under investigation, the 12 euro area countries which introduced euro cash in 2002 accounted for a share of between 97.1% and 98.3% of all euro coins in circulation as at the end of 2016. The subsequent expansion of the euro area is therefore not likely to have had any major impact on the results.

mated hoards dominate coin issuance; it is striking, though, that, especially for €2, 50 cent and 20 cent coins, hoards in Germany account for a larger share of coins in circulation than do hoards in the euro area excluding Germany. These results indicate that one of the primary explanations for the relatively high issuance of coins in Germany is hoarding activity. It is possible that euro coins are being collected relatively frequently in Germany or are being held as a store of value.

Estimates for foreign demand $A_{D,t}$ and $A_{A,t}$ are relevant for the starting point of this paper, i.e. whether more coins have migrated from Germany to the rest of the euro area than vice versa. According to the results, foreign demand for German euro coins is negative in all denominations under observation. Accordingly, more euro coins have migrated to Germany than vice versa, i.e. from Germany to the rest of the euro area. Compared with total coins in circulation, however, the value of coins in circulation abroad is small for all denominations. Aggregated across the coin denominations covered in our study, German euro coins in circulation abroad amount to -€0.5 billion, or -7.6% of the value of German euro coins in circulation in these denominations. Overall, our results indicate that the relatively large German coin issuance is not explained by coin exports to other euro area countries. Neither Germany nor the euro area excluding Germany is able to generate significant coin revenues by exporting coins to other countries.

According to *Table 3*, in the long run 62% of the €2 coins in active circulation in Germany will be German, compared to 44% of the €1 coins, 54% of the 50 cent coins and 61% of the 20 cent coins. It is interesting to note that the current coin shares shown in *Table 2* are already quite close to these theoretically implied thresholds. Thus, we can conjecture that the distribution of national sides has already stabilised in the euro area. It is worth noting that German coins are less prevalent in transaction balances in the euro area excluding Germany than foreign coins in transaction balances in Germany. This is to be expected, given that Germany is smaller than the euro area excluding Germany.

Implications of the model Table 3

	€2 coin	€1 coin	50 cent coin	20 cent coin
$N_{D,t}$	2082	1590	1599	3213
$N_{A,t}$	3733	5388	4302	7565
$T_{D,t}$	832	921	897	1352
$T_{A,t}$	1727	2762	2860	3797
$H_{D,t}$	1360	841	847	2251
$H_{A,t}$	1896	2454	1297	3378
$A_{D,t}$	-110	-172	-145	-390
$A_{A,t}$	110	172	145	390
τ_{DD}	0.62	0.44	0.54	0.61
τ_{AA}	0.78	0.88	0.81	0.86

Source: Author's own calculations.
Note: Data refer to the year 2016. All coin demand data in million pieces.

5 Conclusions

This paper looks at the migration of coins between Germany and the euro area excluding Germany, thereby addressing the question whether the Bundesbank is primarily satisfying domestic coin demand or whether Germany is able to achieve higher coin revenues by exporting coins to other euro area countries.

At end-2017, the total euro coin circulation stood at €28 billion, €8.4 billion of which was put into circulation by the Bundesbank. The share of German euro coins in the total euro coin circulation has remained fairly stable at around 30% since the introduction of euro cash. Given significant and persistent net outflows of coins from Germany to other euro area countries, however, one would expect a rising share of German euro coins. We also analyse long time series on the cumulative net issuance of coins in Germany. A structural break caused by the introduction of euro cash, which would have been expected given a rise in the importance of euro coin migration relative to DM coin migration, is not visible.

Based on the pattern of coin circulation, we formulate the hypothesis that coin flows between Germany and the euro area excluding Germany are balanced. The paper sets out to test this hypothesis using a calibrated coin mixture model. We start by characterising the movements of coins between regions and between transaction balances and coin hoards. This model of coin migration indicates a convergence of the ratio of German coins to foreign coins in transaction balances in Germany as well as in the euro area excluding Germany.

Empirical implications of the model can be derived by setting parameters. The results of the preferred parameter settings indicate that a total of 110 million more €2 coins, 172 million more €1 coins, 145 million more 50 cent coins and 390 million more 20 cent coins have migrated from other euro area countries to Germany than vice versa. These results indicate that net migration of coins between Germany and the rest of the euro area is small. To reflect the fact that the results are derived from assumptions, we implement a set of robustness exercises. The main conclusion of the paper – that net migration of coins between Germany and other parts of the euro area is small – is robust.

According to these results, the theory that the Federal Republic of Germany would obtain particularly large seigniorage income by meeting the demand for coins in other euro area countries does not hold water. Rather, it is national determinants which are primarily responsible for the trend path of national coin issuance in Germany.

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Cash demand in the shadow economy in Germany[1]

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Abstract

An often voiced opinion in the public debate is that cash promotes the shadow economy and is used as a means of financing crime. There are calls for regulatory measures to restrict the use of cash in view of what is presumed to be its widespread use for illegal purposes. Against this backdrop, our own estimations, which are based on the currency demand approach, examine whether demand for German-issued euro banknotes is linked to activities in the shadow economy. For banknote demand in its various definitions only one or two out of the seven shadow economy variables examined here respectively play a role. What stands out is the employment rate in the construction sector, which has a significant influence on the demand for both medium and large-denomination banknotes. Otherwise,

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the demand for small, medium and large-denomination banknotes as well as domestic demand for banknotes, each depend on different shadow economy variables. The shadow economic motives for banknotes demand grow in significance as the denomination size increases.

1 Introduction

Illegal uses of cash refer to those where the surrounding circumstances are not consistent with established law. In the economic literature, illegal uses of cash are mostly studied in connection with estimates of the size of the shadow economy. Estimates put the size of the shadow economy in Germany between around €80 billion and €550 billion. Based on the assumption that transactions in the shadow economy are predominantly settled in cash, that amount in addition to trade in intermediate products represent the annual volume of illegal cash transactions in Germany. However, macroeconomic procedures for studying illegal uses of cash encounter difficulties, inter alia, in adequately accounting for foreign demand and legitimate use of currency as a store of value. It is therefore likely that a number of macroeconomic approaches cannot reliably quantify the volume of illegal cash use. The currency demand approach, which, in an expanded form, serves as the basis for this paper's empirical study, is best suited to estimating illegal cash use. If applied prudently, and if the relevant motives for holding cash are considered, this approach can deliver insights into the importance of illegal motives for cash demand. As a matter of course, the empirical study of the shadow economy is especially challenging, as the illegal activities analysed take place in secret. Accordingly, all results are subject to an above average degree of uncertainty and should only be interpreted cautiously.[2]

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2 This paper presents a short summary of a more extensive study on cash demand in the shadow economy (Bartzsch, Schneider and Uhl, 2019). See also Deutsche Bundesbank (2019).

2 Modelling and simulating euro banknote circulation

In the following, the relationship between the real circulation of German-issued banknotes and the (unobserved) shadow economy is studied.[3] Demand for these banknotes is estimated for the small, medium and large denominations respectively, as well as for domestic circulation. Here, seven different alternative proxy variables (indicators) for the shadow economy are used. In methodological terms, this procedure is associated with the currency demand approach. The present study attempts to largely take into account the criticisms surrounding this approach. Only the extent to which proxy variables for the shadow economy make a statistical explanatory contribution is explored here (partial effects). This is a less ambitious aim than quantifying the exact scale of illegal banknote usage using the currency demand approach.[4] One criticism of the currency demand approach is that it does not adequately capture the various different motives behind shadow economic activities. It is often the case that only the tax and social contributions ratio is considered as an indicator for the shadow economy. In the present analysis, the employment rates in the agricultural and construction sectors, the unemployment rate, the self-employment rate, the total number of crimes and the number of drug-related crimes are also used as indicators. One-off effects such as the financial crisis of 2008 and the decision of the ECB Governing Council on 4 May 2016 to halt the production and distribution of the €500 banknote are still modelled. When using the currency demand approach, it is important to consider all motives for holding cash–particularly foreign demand, if at all relevant. The motives taken into account in this study are outlined in Section 2.1. Demand outside the euro area is depicted by an exchange rate, whilst demand from the rest of the euro area is captured using a residential property price indicator. Alternatively, domestic circulation is used as a dependent variable. This then corresponds

3 Here, German-issued banknotes are the euro banknotes brought into circulation by the Bundesbank. This is the Bundesbank's cumulative net issuance (outpayments less inpayments).

4 Although an attempt was made to determine the value of banknotes in domestic banknote circulation used for shadow economic purposes by means of a dynamic simulation, no meaningful results could be obtained.

to the circulation of German-issued euro banknotes, adjusted for total estimated foreign demand (outside of the euro area and in the rest of the euro area).

The study confines itself to the results of the extensive regression estimations, which illustrate a significant relationship between banknote demand and the shadow economy and are ultimately of interest.[5] In the following section, the data for the econometric analysis as well as the determinants of and estimation methods for banknote demand are explained.[6] This is followed by four sections presenting the results of various models and a summary with concluding remarks.

2.1 Banknote demand: Data, determining factors and estimation methods

A total of five different motives driving banknote demand were identified: 1) shadow economy-related (illegal) motives, 2) transaction motives, 3) the desire for a store of value, 4) the availability of alternative payment instruments, and 5) foreign demand. The following sections explain which variables are used to empirically map these motives.

In the economic literature, the definition of the illicit use of cash is generally an intermediate step when estimating the size of the shadow economy. The starting point for the cash-based method of investigating the shadow economy is the assumption that cash is a suitable payment medium for activities in the shadow economy thanks to its universal acceptance as well as the simple, secure, quick and anonymous transfer options that it provides. Irregularities in the use of cash are consequently taken as an opportunity to determine the extent of the shadow economy (Schneider, 1986). The reversed focus of this analysis is on the shadow economy as an explanatory variable for banknote demand. Transactions in the shadow economy are presumably often conducted in cash so that payments can remain secret (Schneider, 2002). An

5 Documentation of the cointegration analyses for estimations of banknote demand is available from the authors upon request.
6 See also Bartzsch, Seitz and Setzer (2015, Section 4).

increase in shadow economic activities should therefore result in higher currency demand. The shadow economy phenomenon has exceedingly varied characteristics. The burden of taxation and social security contributions is regarded as an important motive for shifting economic activities to the shadow economy. The tax and social contributions ratio is therefore a possible indicator for illegal uses of cash.[7] Other indicators include the unemployment rate, the self-employment rate and the proportions of people employed in the agricultural sector and the construction sector.[8] We also want to cover areas of the shadow economy where the manufacture or trading of the produced goods is illegal. To this end, we investigate the influence of indicators of crime levels taken from the police crime statistics.[9] In our empirical analysis, as alternative approaches, we finally use the following proxy variables for the shadow economy: 1) tax and social security contributions ratio, i.e. wage tax and social contributions as a percentage of households' disposable income, 2) employment rate in the agricultural sector, i.e. the number of persons employed in the agricultural sector as a percentage of all persons in employment, 3) employment rate in the construction sector, i.e. the number of persons employed in the construction sector as a percentage of all persons in employment, 4) unemployment rate, i.e. the number of unemployed persons as a percentage of the civilian labour force, 5) self-employment rate, i.e. the number of self-employed persons as a percentage of all persons in employment, 6) crimes in total, i.e. the total number of recorded crimes, 7) drug-related crimes, i.e. the number of recorded drug-related crimes.

A rising transaction volume is accompanied by increasing banknote demand. Total private consumption, retail sales and gross domestic product serve as transaction variables in traditional studies of banknote demand. In view of the large number of

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7 See Feld and Schneider (2010). This indicator is chosen, for example, in Tanzi (1983) and Schneider (1986).

8 See Ardizzi, Petraglia, Piacenza, Schneider and Turati (2014) as well as Herwartz, Sardà and Theilen (2016).

9 See Federal Criminal Police Office (2016).

cashless payments in the economy, however, these are only rough proxy variables. Therefore, a variable was instead selected that includes the components of the real domestic consumption of households and non-profit institutions serving households, which are predominately paid in cash (real cash consumption). Real cash consumption comprises the following components of the domestic consumption of households and non-profit institutions serving households, as shown in the national accounts: 1) restaurants and hotels, 2) clothing and footwear, 3) recreation and culture, 4) food, as well as 5) other purposes such as healthcare, education, personal care and personal effects.

Aside from their function as a payment medium, banknotes also serve as a store of value. This is particularly true of large-denomination banknotes, and, to a certain extent, medium denomination banknotes too. As banknotes do not bear interest, interest rate levels present themselves as a measure of the opportunity costs associated with holding banknotes. Banknote demand declines as opportunity costs rise. The interest rate for three-month funds in the money market and the yield on ten-year Federal bonds (Bunds), for instance, can be used as measures of the latter. In line with the approach taken by Friedman (1977), a measure is selected for the entire yield curve.[10] This curve is estimated for German Federal securities with a maturity of between three months and 30 years using Svensson's (1994) expanded version of Nelson and Siegel's (1987) method. For further details, see Deutsche Bundesbank (1997).

Cash is in competition with alternative payment instruments. According to the Bundesbank's most recent survey on payment behaviour (Deutsche Bundesbank, 2017), cashless payment instruments are predominantly used to settle higher amounts (€50 and above). However, cash is still used to settle 96% of smaller payment amounts of up to €5 and for the bulk of payments of up to €50. The use of debit cards is increasing. Compared with 2011, their share of turnover rose by around six percent-

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10 Seitz (1998) also recommends the use of such an opportunity cost variable.

age points to 34% in 2017. In principle, card payments can be expected to have a negative influence on banknote demand, as girocards and credit cards are used as substitutes for cash payments. In this vein, Amromin and Chakravorti (2009) found evidence of reduced demand for smaller-denomination banknotes on account of increased debit card usage in the OECD countries. However, bank cards are also used to withdraw money from ATMs. On the one hand, lower transaction costs for withdrawing cash reduce the demand for cash. On the other hand, however, ATMs also make it easier to access cash, thus boosting demand. The impact of card payments on currency demand is therefore unclear. In this analysis, the increasing preference for cashless payments is depicted by domestic card turnover (girocard and credit card). However, these figures are only available as annual data. The quadratic match-sum method was therefore used to convert them into quarterly data. Aside from the familiar girocards and credit cards, new payment instruments now exist, such as contactless card payments, new payment methods for internet purchases and the use of mobile payments.[11] Although the use of contactless card payments and smartphone payments is increasing, consumers' payment habits are changing only slowly. Contactless card payments currently make up 1% of turnover at the point of sale. Very few payments are made by smartphone and with customer or prepaid cards at present. Moreover, new payment instruments are also competing with existing cashless payment instruments. Therefore, no proxy variable for innovative payment methods has been added as a regressor.[12]

The cumulative net issuance of (euro) banknotes by the Bundesbank (German-issued banknotes in circulation) differs from the (estimated) domestic circulation on account of large cross-border inflows and outflows of banknotes.[13] It makes sense to break down the circulation of German-issued banknotes abroad into demand from the rest

11 An overview of alternative payment instruments can be found in Deutsche Bundesbank (2012).
12 In principle, a time trend can be used as a rough approximation for the process of financial innovation.
13 See Bartzsch and Uhl (2017).

of the euro area and demand from countries outside the euro area. There is also demand for German-issued (euro) banknotes in other euro area countries, as they are a perfect substitute for the banknotes issued by other Eurosystem central banks. In other words, banknote demand in one euro area country can be met through inflows of banknotes from another euro area country. The transaction-related share of this demand is depicted using house prices, i.e. the ECB's residential property price indicator excluding Germany. Anecdotal evidence suggests that properties are also commonly paid for in cash in some of these countries.[14] If buyers are domiciled in Germany, this results in banknotes being exported from Germany. These buyers may be Germans, or alternatively EU citizens from the rest of the euro area now residing in Germany who purchase properties in their home countries with banknotes brought with them from Germany. Such transactions are likely to be predominantly settled with large-denomination banknotes. The other component of foreign demand comes from countries outside the euro area. In the absence of a variable that directly displays demand from many different countries, the real effective exchange rate of the euro against the currencies of the EER-12 is chosen as a proxy variable for foreign banknote circulation outside the euro area. For more information, see also Fischer et al. (2004). An appreciation of the euro should make it more attractive and should therefore be accompanied by greater demand for euro cash in non-euro area countries.

As an alternative to including the regressors "exchange rate" and "ECB's residential property price indicator for the euro area excluding Germany" in banknote demand estimations, German-issued banknote circulation was adjusted for the estimated foreign circulation. Domestic circulation estimated in this way corresponds to the cumulative net issuance of banknotes by the Bundesbank less the cumulative net

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14 For information pertaining to Spain, see Stücklin (2017). Flannigan and Parsons (2018) estimate demand for large-denomination banknotes in Australia, Canada and the United Kingdom, respectively, using ARDL models. Their chosen regressors include, amongst others, property prices as a proxy variable for household wealth. Using this approach, they identify a significant (positive) wealth effect for demand for the Canadian $100 bill.

deliveries of euro banknotes to countries outside the euro area by international banknote wholesalers in Germany less the estimated German net exports of banknotes taken abroad by travellers. The regressions for the estimated domestic circulation can be found in Section 2.5.

It would seem reasonable to assume that the coefficients of the above-described explanatory variables differ from each other for the individual banknote denominations. For instance, the transaction motive is particularly significant for small and medium-value denominations. For large denominations, by contrast, having a store of value is presumably the strongest motive. Additionally, substitutional effects can be expected between banknotes of similar value. For this reason, the following alternative dependent variables are used for the estimates: the real stocks (cumulative net issuance by the Bundesbank) of small, medium and large denominations. Another approach involves using real domestic banknote circulation[15] as a dependent variable.[16] The denominations are classified as follows: €5-€20 banknotes as small denominations, €50 and €100 banknotes as medium denominations and €200 and €500 banknotes as large denominations. This classification system was chosen as ATMs do not tend to issue larger denominations and are predominantly used to replenish transaction balance holdings.[17] The large denominations are thus unlikely to be used to conduct regular transactions. Furthermore, the €50 banknote is likely to be the smallest denomination used (amongst other purposes) as a store of value.

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15 Domestic banknote circulation is the difference between cumulative net issuance and estimated total foreign circulation.

16 “Real stock” refers to the deflated stock in terms of value. It is obtained by dividing the nominal stock (cumulative net issuance in terms of value or banknote circulation in terms of value) by the deflator of domestic cash consumption by households and non-profit institutions serving households.

17 For a cash study of several countries using a similar classification scheme in which the transaction motive is distinguished from the desire to have a store of value, see Amromin und Chakravorti (2009). The authors identify medium banknote denominations by establishing which denominations are predominantly withdrawn from ATMs. Denominations exceeding this value are classed as “large”, while those falling short (including coins) are classed as “small”.

A possible criticism of the currency demand approach is that one-off effects are not taken into account. In this analysis, by contrast, one-off effects are indeed modelled. The financial crisis of 2008 is shown, as is the decision of the ECB Governing Council on 4 May 2016 to halt the production and distribution of the €500 banknote. The impact of the financial crisis on banknote circulation is modelled using the following dummy variables. One dummy variable takes the value of 1 in the fourth quarter of 2008, but is otherwise equal to zero. It models the increase in banknote circulation in this quarter following the escalation of the financial crisis. The ensuing scaling back or further restocking of this hoard is modelled with dummy variables for the subsequent quarters. On 4 May 2016, the Governing Council of the ECB decided to discontinue the production and issuance of the €500 banknote towards the end of 2018. As a result of this decision and the previous months of public debate surrounding the issue, the circulation of the €500 banknote declined from the first quarter of 2016. In some cases, switches to €200 and €100 banknotes also took place. The effect of this on large and medium denominations is modelled using two quarterly dummy variables.

Description of data

Table 1

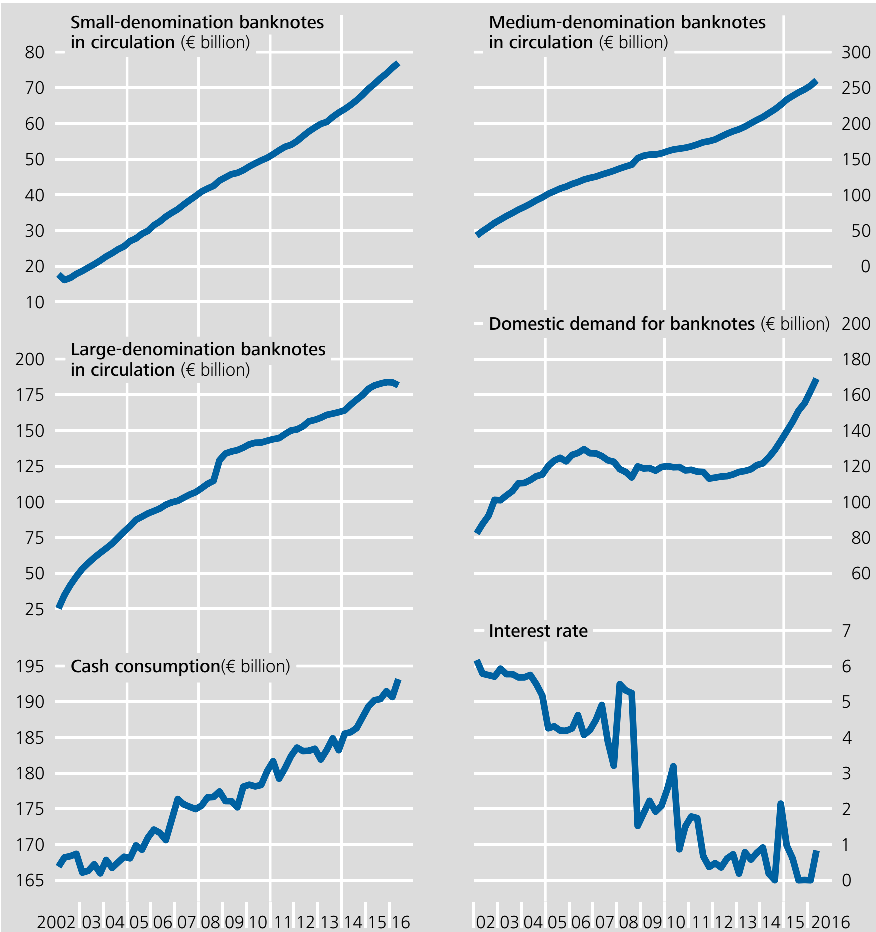
Variable	Description	Stationary transformation for the regression estimations
Circulation of small-denomination banknotes	Real circulation of €5, €10 and €20 banknotes issued by the Bundesbank in € billion (seasonally adjusted). Sources: Deutsche Bundesbank and authors' own calculations.	Logarithmic first difference (logarithmic growth rate)
Circulation of medium-denomination banknotes	Real circulation of €50 and €100 banknotes issued by the Bundesbank in € billion (seasonally adjusted). Sources: Deutsche Bundesbank and authors' own calculations.	Logarithmic first difference (logarithmic growth rate)
Circulation of large-denomination banknotes	Real circulation of €200 and €500 banknotes issued by the Bundesbank in € billion (seasonally adjusted). Sources: Deutsche Bundesbank and authors' own calculations.	Logarithmic first difference (logarithmic growth rate)
Domestic banknote circulation	Real (estimated) domestic circulation of euro banknotes in € billion (seasonally adjusted). Sources: Deutsche Bundesbank and authors' own calculations.	Logarithmic first difference (logarithmic growth rate)

Cash consumption	Real cash consumption in € billion (seasonally adjusted). Sources: Federal Statistical Office and authors' own calculations.	Logarithmic first difference (logarithmic growth rate)
Interest rate	Shift parameter derived from the estimated yield curve, which stands for the generally prevailing interest rate level. Source: Deutsche Bundesbank.	First difference
Card turnover	Domestic card turnover from girocards and credit cards in € billion. Sources: PaySys Consultancy GmbH and authors' own calculations.	Logarithmic first difference (logarithmic growth rate)
Exchange rate	Real effective exchange rate of the euro against the currencies of the EER-12. Source: Deutsche Bundesbank.	Logarithmic first difference (logarithmic growth rate)
Property prices in the rest of the euro area	ECB's residential property price indicator for the euro area excluding Germany. Source: European Central Bank.	Logarithmic first difference (logarithmic growth rate)
Tax and social security contributions ratio	Wage tax and social contributions as a percentage of households' disposable income (seasonally adjusted). Sources: Deutsche Bundesbank, Federal Statistical Office and authors' own calculations.	
Employment rate in the agricultural sector	Number of persons employed in the agricultural sector as a percentage of all persons in employment (seasonally adjusted). Sources: Deutsche Bundesbank, Federal Statistical Office and authors' own calculations.	
Employment rate in the construction sector	Number of persons employed in the construction sector as a percentage of all persons in employment (seasonally adjusted). Sources: Deutsche Bundesbank, Federal Statistical Office and authors' own calculations.	
Unemployment rate	Number of unemployed persons as a percentage of the civilian labour force (seasonally adjusted). Source: Federal Employment Agency.	
Self-employment rate	Number of self-employed persons as a percentage of all persons in employment (seasonally adjusted). Sources: Deutsche Bundesbank, Federal Statistical Office and authors' own calculations.	
Crimes in total	Total number of recorded crimes. Sources: police crime statistics and authors' own calculations.	Logarithmic first difference (logarithmic growth rate)
Drug-related crimes	Number of recorded drug-related crimes. Sources: police crime statistics and authors' own calculations.	Logarithmic first difference (logarithmic growth rate)

Source: Own depiction

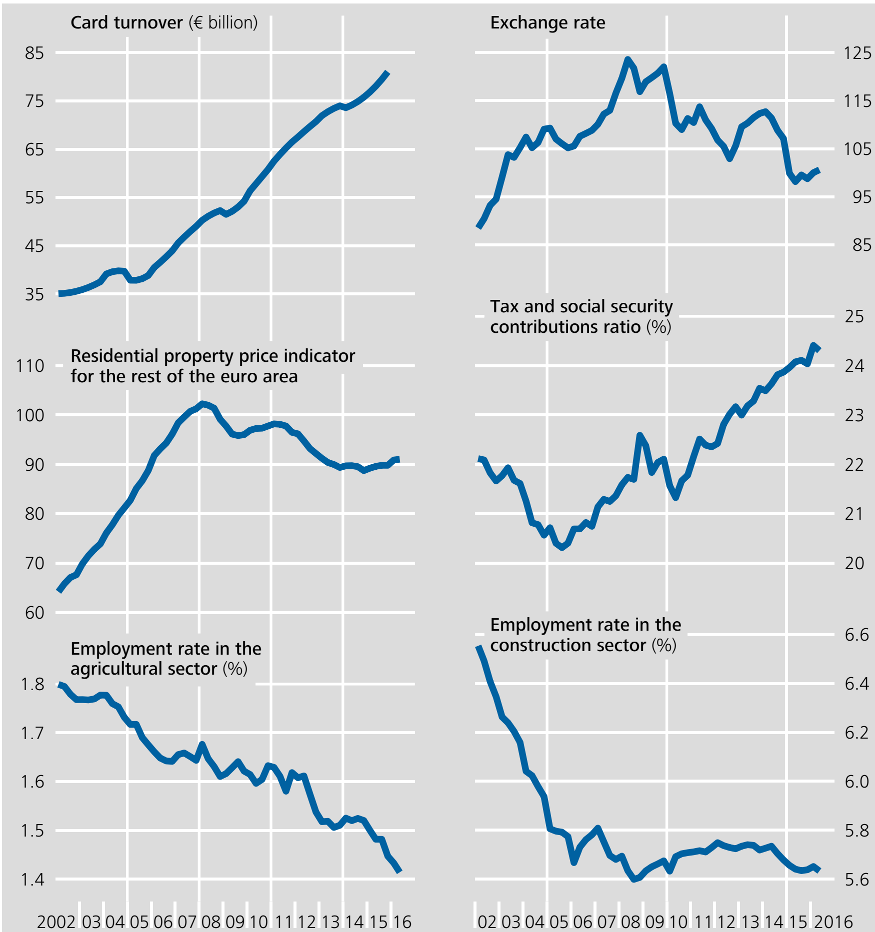
Time series

Figure 1.1



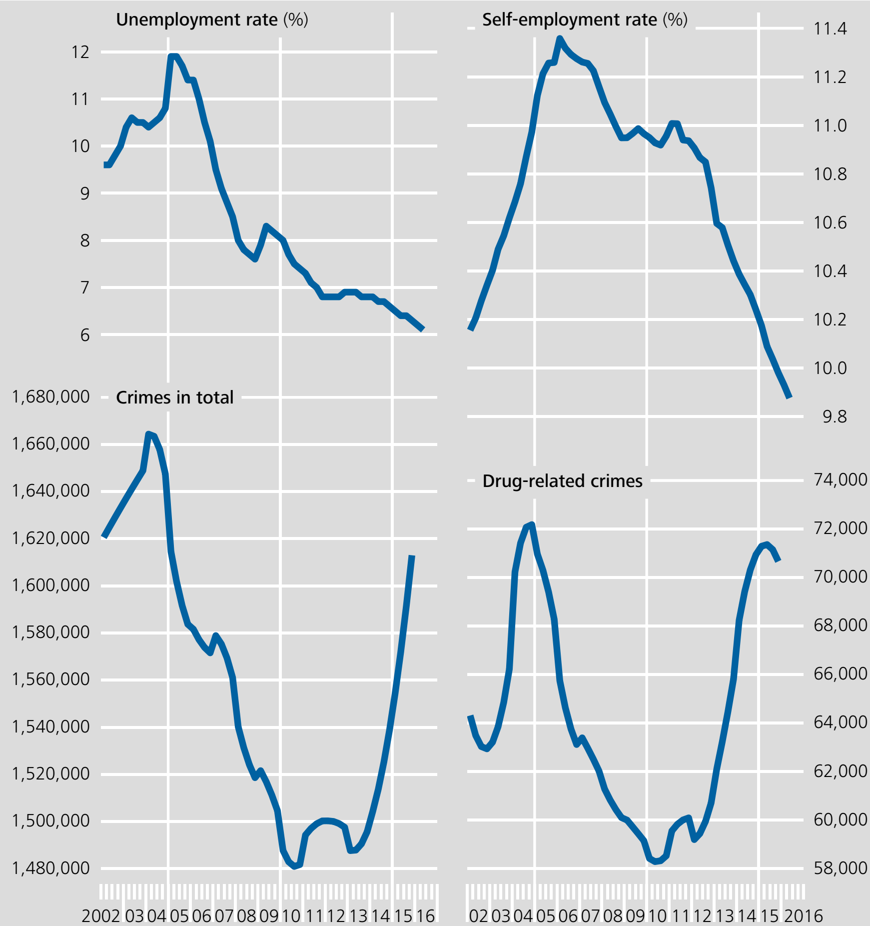
Time series

Figure 1.2



Time series

Figure 1.3



Sources: Federal Employment Agency, Deutsche Bundesbank, European Central Bank, PaySys Consultancy GmbH, police crime statistics, Federal Statistical Office and authors'own calculations.

Quarterly data were used. Time series which were only available in the form of monthly or annual data were converted to quarterly data. The dataset essentially comprises the period from the first quarter of 2002 to the second quarter of 2016. The data used to estimate banknote demand are, as usual, adjusted for seasonal and calendar effects, to the extent that the time series display any such effects. The estimates are made using a real specification; in other words, long-term price homogeneity is assumed. The data are described in *Table 1*. A graphic representation of the time series can be found in *Figure 1*.

Finally, the estimation methods employed in Sections 2.2 to 2.5 are described. A distinction should be made between the two non-stationary proxy variables for the shadow economy "crimes in total" and "drug-related crimes" on the one hand and the remaining five stationary proxy variables for the shadow economy on the other. Here, the first group is referred to as "shadow economy–illegal" and the second group as "shadow economy–legal production". Alternatively, different combinations of control variables are added to each of the eight combinations of endogenous variables and "shadow economy–illegal".[18] Each of these variables are then tested for cointegration. In the event that no cointegration relationship is identified within the system of equations, i.e. no vector error correction model is found, the cointegration analysis is performed with individual equations.[19] If no cointegration relationship is found there either, dynamic regression models, more specifically autoregressive distributed lag (ARDL) models, are estimated for banknote demand using the general-to-specific approach.[20] To avoid the problem of omitted variables, two proxy variables for the shadow economy were included as regressors in the starting specification of the models; one from the "shadow economy–legal production" group and

18 The control variables include all the exogenous variables (determining factors of banknote demand) with the exception of the proxy variables for the shadow economy.
19 Documentation of the cointegration analyses is available from the authors upon request.
20 Distortions resulting from omitted variables can be avoided with the use of the general-to-specific approach. A comprehensive overview of this approach can be found in Campos et al. (2005).

one from the "shadow economy–illegal" group.[21] Finally, the ARDL models estimated in this manner are transferred from the reduced-form equation to the static long-run equation.[22] The long-run multipliers of the shadow economy variables in terms of banknote circulation, which are ultimately of interest, can be ascertained from this equation.[23] No cointegration analysis is performed for the proxy variables from the "shadow economy–legal production" group on account of their stationarity. The starting specifications of the ARDL models take the following general form:

$$\begin{aligned}(1) \qquad y_t = {} & c + \alpha_1 y_{t-1} + \alpha_2 y_{t-2} + \alpha_3 y_{t-3} + \alpha_4 y_{t-4} + x_t' \beta_1 + x_{t-1}' \beta_2 \\ & + \gamma_1 z_{prod,t} + \gamma_2 z_{prod,t-1} + \gamma_3 z_{illegal,t} + \gamma_4 z_{illegal,t-1} + u_t, \quad t = 1,\dots,T.\end{aligned}$$

Here, y_t stands for the demand for banknotes as an endogenous variable, c is the constant term, x_t designates the vector of the control variables, $z_{prod,t}$ represents a shadow economy variable from the "shadow economy–legal production" group, $z_{illegal,t}$ represents a shadow economy variable from the "shadow economy–illegal"

21 In principle, it makes sense to add all of the shadow economy variables into the regressions together to avoid potential problems resulting from omitted variables. However, problems stemming from multicollinearity can subsequently arise. If the individual proxy variables are highly correlated with the shadow economy, this means that they are also highly correlated with each other. As a result, the estimation of the coefficients can be very imprecise. On account of the relatively low number of observations (fewer than 60), it was decided not to incorporate all of the shadow economy variables into the starting specifications of the regressions as a whole, but rather to include just two in each case. A well-specified ARDL model could not be estimated for the demand for large-denomination banknotes using such starting specifications. For this denomination, therefore, only one of the seven shadow economy variables was added per regression. As a result, seven regression models were estimated, the starting specifications of which only differ in terms of the shadow economy variable.

22 The static long-run equation is also known as a long-run static equilibrium solution. The system is defined as having reached its equilibrium point when the variables have become stable or stationary (steady state) and no longer change. Where variables are defined as growth rates, these are steady state growth rates.

23 It can be deduced from the reduced form of the model how the dependent variable in the current period t would react to a change (assumed here to be persistent) in a current exogenous variable (impact multiplier). Over the autoregressive structure of the model, the dependent variable changes during the subsequent periods t+1, t+2, etc. The corresponding changes are known as dynamic multipliers. The sequence of these dynamic multipliers converges towards the long-term multiplier over time. This shows the long-term effect that a persistent change of one exogenous variable has on the dependent variable.

group, and u_t is the residual. The alphas, betas and gammas are the corresponding coefficients. The control variables include all the exogenous variables with the exception of the shadow economy variables. The variables are fed into the regression after being transformed into stationary variables as described in *Table 1*.

The regression estimations described in the following sections are summarised in *Table 2* for banknote circulation according to denomination and in *Table 3* for domestic circulation. These tables contain the ARDL models estimated on the basis of equation (1), the corresponding static long-run equations and the results of the diagnostic tests of the dynamic regression models. The explanatory variables are grouped into the following blocks: deterministic control variables, lagged endogenous variables, stochastic control variables and proxy variables for the shadow economy. The endogenous variables, i.e. dependent variables or rather variables to be explained, are listed in the first line of *Table 2*.

2.2 Structural models for demand for small-denomination banknotes

The two shadow economy variables "unemployment rate" and "crimes in total" as driving forces have a highly significant positive impact on the logarithmic growth rate in real circulation of small-denomination banknotes, see model (1) in *Table 2*. They are also the only regressors. The model passes the diagnostic tests. The null hypotheses of uncorrelated, homoscedastic and normally distributed residuals are not rejected. The Ramsey RESET test does not indicate any misspecification in the model. The adjusted R^2 value of 0.69 is satisfactory, but is considerably lower than in models (2) to (5) for medium-denomination and large-denomination banknotes. This could be a result of the difficulty in modelling the domestic migration of these banknotes.[24] Since the ARDL model (1) does not contain any lagged endogenous variables, it

24 "Domestic migration" refers to the migration of euro banknotes within the euro area. The Bundesbank's large share of the issuance of small-denomination banknotes is indicative of considerable export of these banknotes to the rest of the euro area.

results directly (i.e. with no further transformation) in the associated static long-run equation that is ultimately of interest here. The long-run multiplier of the logarithmic growth rate of the total number of crimes in relation to the logarithmic growth rate of real circulation of small-denomination banknotes has a value of 0.70. This is to be interpreted as follows: if there is a sustained rise of 1 percentage point in the logarithmic growth rate of the total number of crimes, the logarithmic growth rate of real circulation of small-denomination banknotes rises by 0.7 percentage point over the long term. In order to classify this result, it is helpful to take a look at the development of both time series. In the estimation period, the logarithmic growth rate of the total number of crimes fluctuated within a range of -2.0% to 1.3%. In the estimation period, the logarithmic growth rate of real circulation of small-denomination banknotes was within an interval of 1% to 6%, but was within a narrower range of around 1% to 2.5% from 2009. The long-run multiplier of the shadow economy variable "crimes in total" in relation to the circulation by value of small-denomination banknotes can therefore be considered economically significant.

The long-run multiplier of the shadow economy variable "unemployment rate" in relation to the logarithmic growth rate of real circulation of small-denomination banknotes in the static long-run equation has a value of 0.007. This is to be interpreted as follows: if there is a sustained rise of 1 percentage point in the unemployment rate, the logarithmic growth rate of real circulation of small-denomination banknotes rises by 0.7 percentage point over the long term.[25] In order to classify this result, another look should be taken at the development of both time series. In the estimation period, the unemployment rate fell from 10.5% to 6.1%, temporarily rising from 10.8% to 11.9% in the first quarter of 2005 (see *Figure 1*). The long-run multiplier of the shadow economy variable

25 It should be noted that the unemployment rate is quoted in percentage points while the logarithmic growth rate of real circulation of small-denomination banknotes is quoted as a percentage. If, for example, the latter rises from 0.01 or 1% to 0.017 or 1.7%, this constitutes a rise of 0.7 percentage point.

"unemployment rate" in relation to the real circulation of small-denomination banknotes is therefore likely to be economically significant.

2.3 Structural models for demand for medium-denomination banknotes

A long-run equilibrium relationship (cointegration relationship) with the shadow economy variable "drug-related crimes" (and other variables) was found for the demand for medium-denomination banknotes. Dynamic regression models show a statistically significant influence on demand for medium-denomination banknotes only for the shadow economy variable "employment rate in the construction sector" as a driving force, see models (2) and (3) in *Table 2*. In line with the results of surveys on payment behaviour, card payments play a role in the demand for medium-denomination banknotes. The theoretical uncertainty regarding the sign of the card payments coefficient is reflected in the estimations.

A cointegration relationship (long-run equilibrium relationship) with the variables "card turnover", "drug-related crimes" and "house prices in the euro area excluding Germany" was found for real demand for medium-denomination banknotes; see model (3) in *Table 2*. All of the coefficients are highly significant and the positive signs are consistent with the theory or can be theoretically justified. The elasticity of real demand for medium-denomination banknotes in relation to the residential property price indicator for the rest of the euro area has a value of 1.3. If this indicator increases by 1%, real demand for medium-denomination banknotes rises correspondingly–and slightly disproportionately–by 1.3%. Real demand for medium-denomination banknotes is positively dependent on card turnover with an elasticity of 1. The positive effect of easier access to ATMs apparently outweighs the negative effects of card payments as a substitute for cash payments and lower transaction costs for obtaining cash. If there is a sustained rise of 1% in the number of drug-related crimes, the real circulation of medium-denomination banknotes also rises by just over 1% over the long term. In other words, as is the case for card turnover, the elasticity of real circulation of medium-denomination

Results of the regression estimations for the individual denominations — Table 2

Endogenous variable	Small-denomination banknotes in circulation	Medium-denomination banknotes in circulation		Large-denomination banknotes in circulation	
ARDL model	(1)	(2)	(3)	(4)	(5)
Constant term	- 0.03***	- 0.11*	-17.31***	- 0.08***	- 0.28***
Dummy variable for Q4 2008		0.04***		0.10***	0.11***
Dummy variable for Q1 2009				- 0.03***	- 0.02**
Dummy variable for Q2 2009				- 0.03***	
Dummy variable for Q3 2009		- 0.02***			
Dummy variable for Q4 2009		- 0.02***			
Dummy variable for Q2 2016					- 0.02**
Endogenous variable lagged by one period				0.54***	0.45***
Endogenous variable lagged by four periods		0.34***			
Residential property prices in the euro area excluding Germany			1.31***		
Card turnover		- 0.19***	1.07***		
Card turnover lagged by one period				- 0.18**	
Euro exchange rate lagged by one period				0.09**	
Unemployment rate	0.007***				
Employment rate in the agricultural sector				0.06***	
Employment rate in the construction sector		- 0.04**			
Employment rate in the construction sector lagged by one period		0.06***			0.05***
Crimes in total lagged by one period	0.70***				
Drug-related crimes			1.10***		

Static long-run equation for the regression model	(1)	(2)	(3)	(4)	(5)
Constant term	-0.03***	- 0.17**		- 0.17 ***	- 0.51***
Dummy variable for Q4 2008		0.07***		0.22***	0.20***
Dummy variable for Q1 2009				- 0.08***	- 0.04**
Dummy variable for Q2 2009				- 0.06***	
Dummy variable for Q3 2009		- 0.02***			
Dummy variable for Q4 2009		- 0.03***			
Dummy variable for Q2 2016					- 0.03**
Card turnover		- 0.29***		- 0.38**	
Euro exchange rate				0.21**	
Unemployment rate	0.007***				
Employment rate in the agricultural sector				0.12***	
Employment rate in the construction sector		0.033**			0.09***
Crimes in total	0.70***				
Diagnostic tests	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Number of observations	55 (Q3 2002-Q1 2016)	51 (Q2 2003-Q4 2015)	53 (Q3 2002-Q3 2015)	55 (Q3 2002-Q1 2016)	56 (Q3 2002-Q2 2016)
Adjusted R^2	0.69	0.92	0.99	0.96	0.96
Prob (F-statistic)	0.00	0.00		0.00	0.00
Breusch-Godfrey autocorrelation test: LM (12) [p value]	19.87 [0.07]	15.55 [0.21]		11.19 [0.51]	12.96 [0.37]
Jarque-Bera test of normal distribution: JB [p value]	5.62 [0.06]	4.81 [0.09]		0.08 [0.96]	1.85 [0.40]
White-Test of heteroscedasticity: Obs*R^2 statistic [p value]	5.21 [0.39]	7.37 [0.97]		25.23 [0.09]	14.31 [0.28]
Ramsey RESET test:					
F-statistic [p value]	1.52 [0.23]	0.52 [0.60]		2.73 [0.076]	0.41 [0.67]
Likelihood ratio [p value]	3.25 [0.20]	1.28 [0.53]		6.30 [0.043]	0.96 [0.62]

Notes: *** significant at 1%, ** significant at 5%, * significant at 10%.
With the exception of model (3), the variables undergo stationary transformation as described in Table 1. Unlike the other models, model (3) is not an ARDL model, but a cointegration equation. As a result, model (3) is already available in the form of a static long-run equation. All of the variables in that model are logged and non-stationary.
Source: Authors' own calculations.

banknotes in relation to the number of drug-related crimes has a value of 1. This positive, proportionally elastic influence of the number of drug-related crimes on real demand for medium-denomination banknotes can be considered economically significant.

According to dynamic regression model (2) in *Table 2*, the logarithmic growth rate of real circulation of medium-denomination banknotes is explained by its value lagged by four periods, the logarithmic growth rate of card turnover, as well as the current value of the employment rate in the construction sector and the value lagged by one period. The three dummy variables depict the rise in real demand for medium-denomination banknotes as a result of the financial crisis in the fourth quarter of 2008 as well as the complete reduction of this additional demand in the second half of 2009. The adjusted R^2 value of 0.92 is high and the model passes the diagnostic tests. The null hypotheses of uncorrelated, homoscedastic and normally distributed residuals are not rejected. The Ramsey RESET test does not indicate any misspecification in the model. Unlike in cointegration model (3), real demand for medium-denomination banknotes falls as card turnover rises. Here, the negative effect of card payments as a substitute for cash payments and the lower transaction costs for obtaining cash therefore outweigh the positive effect of easier access to ATMs. Due to the differing signs, the model cannot be used to ascertain whether a (sustained) rise in the ratio of persons employed in the construction sector leads to an increase in the logarithmic growth rate of real circulation of medium-denomination banknotes, as would be expected in theory. Insight into this is first provided by the static long-run equation.

According to the equation, the long-run multiplier of the shadow economy variable “employment rate in the construction sector” in relation to the logarithmic growth rate of real circulation of medium-denomination banknotes has a value of 0.033. This coefficient is significant and has a positive sign, as would be expected in theory. This is to be interpreted as follows: if there is a sustained rise of 1 percentage point in the ratio of persons employed in the construction sector, the logarithmic growth rate of real circulation of medium-denomination banknotes rises by 3.3 percentage points over the long term.[26] In order to classify this result, it is helpful to take a look at the development of both time series. In the estimation period, the ratio of persons employed in the construction sector fell from 6.2% to 5.6% (see *Figure 1*) and the logarithmic growth rate of real circulation of medium-denomination banknotes was within an interval of 0% to 7%. On balance, the long-run multiplier of the shadow economy variable "employment rate in the construction sector" in relation to real circulation of medium-denomination banknotes can therefore be considered economically significant. The long-run multiplier of card turnover with a value of -0.29 is to be interpreted as follows: if there is a rise of 1 percentage point in the logarithmic growth rate of card turnover, the logarithmic growth rate of real demand for medium-denomination banknotes falls by 0.29 percentage point.

2.4 Structural models for demand for large-denomination banknotes

There is a statistically significant relationship between real demand for large-denomination banknotes and the shadow economy for the shadow economy variables "employment rate in the agricultural sector" and "employment rate in the construction sector"; see models (4) and (5) in *Table 2*. As in the case of the medium denominations, the regression estimates for real demand for large-denomination banknotes have greater explanatory power than the estimates for the small denominations, as foreign demand can be modelled more effectively. In line with the results of surveys on payment behaviour, card payments play a role in the demand for large-denomination banknotes. According to dynamic regression model (4), the logarithmic growth rate of real circulation of large-denomination

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26 It should be noted that the ratio of persons employed in the construction sector is quoted in percentage points while the logarithmic growth rate of real circulation of medium-denomination banknotes is quoted as a percentage. If, for example, the latter rises from 0.01 or 1% to 0.043 or 4.3%, this constitutes a rise of 3.3 percentage points.

banknotes is explained by its value lagged by one period, the value of the logarithmic growth rate of card turnover lagged by one period, the value of the exchange rate lagged by one period, as well as the ratio of persons employed in the agricultural sector. The dummy variables for the fourth quarter of 2008 to the second quarter of 2009 depict the rise in real demand for large-denomination banknotes as a result of the financial crisis in the fourth quarter of 2008 as well as the partial reduction of this additional demand in the first half of 2009. As a result of the financial crisis, the logarithmic growth rate of real demand for large-denomination banknotes rose by an additional 10 percentage points over the short term (from 2% in the third quarter of 2008 to 12% in the fourth quarter of 2008). The positive signs of the coefficient of the ratio of persons employed in the agricultural sector and of the exchange rate are consistent with the theory. As is also the case in the dynamic regression model for demand for medium-denomination banknotes, the coefficient (of the logarithmic growth rate) of card turnover is negative. The negative effect of card payments as a substitute for cash payments and the lower transaction costs for obtaining cash again outweigh the positive effect of easier access to ATMs. The adjusted R^2 value of 0.96 is high and the model passes most of the diagnostic tests. The Ramsey RESET test for general misspecification does not produce a clear result, however.[27]

The long-run multiplier of the shadow economy variable "employment rate in the agricultural sector" in relation to the logarithmic growth rate of real circulation of large-denomination banknotes is to be interpreted as follows: if there is a sustained rise of 1 percentage point in the ratio of persons employed in the agricultural sector, the logarithmic growth rate of real circulation of large-denomination

27 The null hypothesis that the model is not misspecified is in fact not rejected by the F statistic (at the 5% level), but by the likelihood ratio.

banknotes rises by 12 percentage points over the long term.[28] In order to classify this result, it is helpful to take a look at the development of both time series. In the estimation period, the ratio of persons employed in the agricultural sector fell from just under 1.8% to just over 1.4% (see *Figure 1*) and the logarithmic growth rate of real circulation of large-denomination banknotes was within an interval of 0% to 3%, disregarding both the strong growth in the initial quarters of the estimation period, which were still being affected by the introduction of euro cash, and the strong growth in the fourth quarter of 2008 (compared to the preceding quarter) as a result of the financial crisis. In particular, the long-run multiplier of the shadow economy variable "employment rate in the agricultural sector" in relation to the logarithmic growth rate of real circulation of large-denomination banknotes is even slightly higher than the (short-term) impact of the financial crisis in the fourth quarter of 2008, which, according to the regression estimation, caused this growth rate to rise by an estimated 10 percentage points. It is therefore certain that the long-run multiplier is economically significant. However, this result is subject to the potential misspecification in the underlying reduced-form model, as discussed above. Furthermore, the effect is also not entirely attributable to shadow economic motives, as cash is typically used in the agricultural sector for legal payments as well. The long-run multiplier of the logarithmic growth rate of card turnover is (in absolute terms) around twice as high as the long-run multiplier of the exchange rate.

Dynamic regression model (5) displays the estimated relationship between the growth rate of real circulation of large-denomination banknotes and the employment rate in the construction sector as a proxy variable for the shadow economy. The adjusted R^2 value of 0.96 is high and the model passes all of the diagnostic tests.

28 It should be noted that the ratio of persons employed in the agricultural sector is quoted in percentage points while the logarithmic growth rate of real circulation of large-denomination banknotes is quoted as a percentage. If, for example, the latter rises from 0.01 or 1% to 0.13 or 13%, this constitutes a rise of 12 percentage points.

The ratio of persons employed in the construction sector is introduced into the regression with its value lagged by one period. It is highly significant and, as expected in theory, positive. According to the regression estimation, the additional growth in real circulation of large-denomination banknotes as a result of the financial crisis amounted to 11 percentage points in the fourth quarter of 2008. It is estimated that the discontinuation of the €500 banknote caused the logarithmic growth rate of real circulation of large-denomination banknotes to decline by 2 percentage points.

The long-run multiplier of the shadow economy variable "employment rate in the construction sector" in relation to the logarithmic growth rate of real circulation of large-denomination banknotes is to be interpreted as follows: if there is a sustained rise of 1 percentage point in the ratio of persons employed in the construction sector, the logarithmic growth rate of real circulation of large-denomination banknotes rises by 9 percentage points over the long term.[29] In order to classify this result, it is again helpful to take a look at the development of the time series. From the third quarter of 2002 to the first quarter of 2006, the ratio of persons employed in the construction sector fell from around 6.4% to around 5.7% and then remained more or less constant (see *Figure 1*). In addition, the long-run multiplier for the shadow economy variable "employment rate in the construction sector" in relation to real circulation of large-denomination banknotes is almost as large as the short-term impact of the financial crisis in the autumn of 2008. It is therefore safe to say that this long-run multiplier is economically significant.

In comparison to the small denominations, the regression estimates for real demand for larger-denomination banknotes have greater explanatory power in terms of a higher coefficient of determination. Foreign demand can be modelled more

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29 It should be noted that the ratio of persons employed in the construction sector is quoted in percentage points while the logarithmic growth rate of real circulation of large-denomination banknotes is quoted as a percentage. If, for example, the latter rises from 0.01 or 1% to 0.10 or 10%, this constitutes a rise of 9 percentage points.

effectively for these denominations. In line with the results of surveys on payment behaviour, card payments play a role in the demand for medium-denomination and large-denomination banknotes.

2.5 Structural models for domestic demand for banknotes

In addition to the models for the demand by denomination for euro banknotes issued by the Bundesbank described in Sections 2.2 to 2.4, domestic demand for banknotes (real domestic circulation) is modelled in this section.[30] This serves two purposes. First, it takes account of the difficulty in appropriately depicting foreign circulation in regressions. To some extent, the exchange rate is likely to represent a good means of capturing the circulation of German-issued euro banknotes outside the euro area. By contrast, the demand for German-issued euro banknotes in the rest of the euro area (excluding Germany) is difficult to depict.[31] Second, domestic circulation as a regional component of German-issued banknotes in circulation is already a topic of interest in and of itself. In this context, particular attention should be paid to the relationship between domestic circulation and the shadow economy. In order to do so, partial effects will be estimated in this section as they were in the three previous sections. Real domestic circulation, which is used as the dependent variable, corresponds–before deflation–to the difference between the value of the cumulative net banknote issuance by the Bundesbank and the (total) foreign circulation of German-issued euro banknotes as estimated in Bartzsch and Uhl (2017).[32] Unlike total banknote circulation (cumulative net issuance by the Bundesbank), domestic banknote circulation cannot be decomposed into (small, medium and large) denominations, as the relevant estimates are not available.

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30 As the Bundesbank meets all of the demand for banknotes and Germany is a net exporter of euro banknotes, domestic demand for euro banknotes corresponds to domestic circulation of euro banknotes.

31 The total domestic migration of euro banknotes in the euro area–and not only German net exports–is difficult to estimate.

32 The regressors for foreign circulation can therefore be omitted. This procedure is equivalent to introducing the foreign circulation estimated in Bartzsch and Uhl (2017) as an additional regressor in the estimation equation for the total circulation of German-issued banknotes and restricting its coefficients to a value of 1.

Results of the regression estimations for domestic circulation

Table 3

Endogenous variable	Domestic demand
ARDL model	**(6)**
Constant term	- 0.10***
Dummy variable for Q4 2008	0.04***
Endogenous variable lagged by one period	0.21**
Endogenous variable lagged by two periods	0.22**
Endogenous variable lagged by four periods	0.35***
Cash consumption lagged by one period	0.55**
Card turnover lagged by one period	- 0.30**
Interest rate	- 0.005**
Tax and social security contributions ratio	0.005***
Number of observations	52 (Q2 2003-Q1 2016)
Adjusted R^2	0.71
Prob (F-statistic)	0.00
Breusch-Godfrey autocorrelation test:	
LM (12) [p value]	15.89 [0.20]
Jarque-Bera test of normal distribution:	
JB [p value]	1.77 [0.41]
White test of heteroscedasticity:	
Obs*R^2 statistic [p value]	34.84 [0.52]
Ramsey RESET test:	
F-statistic [p value]	0.94 [0.40]
Likelihood ratio [p value]	2.32 [0.31]

Static long-run equation for the regression model	**(6)**
Constant term	- 0.46*
Dummy variable for Q4 2008	0.19
Cash consumption	2.42
Card turnover	- 1.35*
Interest rate	- 0.02
Tax and social security contributions ratio	0.022**

Notes: *** significant at 1%, ** significant at 5%, * significant at 10%.
As described in Table 1, the variables in the ARDL model (6) undergo stationary transformation.
Source: Authors' own calculations.

There is a statistically significant relationship between domestic demand for banknotes and the shadow economy for the shadow economy variable "tax and social security contributions ratio"; see also model (6) in *Table 3*. In this dynamic regression model, the logarithmic growth rate of real domestic banknote circulation is explained by its lagged values, the logarithmic growth rate of cash consumption lagged by one period, the logarithmic growth rate of card turnover lagged by one period, the change in interest rates, and the tax and social contributions ratio, which serves as a proxy variable for the shadow economy. All of the regressors are (at least) statistically significant. As traditional motives for banknote demand, transactions and hoarding now play a role. However, in the regression estimations by denomination, it is likely that these motives are obscured by foreign circulation. As is also the case in the dynamic regression models for demand for medium-denomination and large-denomination banknotes, the coefficient (of the logarithmic growth rate) of card turnover is negative. The negative effects of card payments as a substitute for cash payments and the lower transaction costs for obtaining cash again outweigh the positive effect of easier access to ATMs. A rise of 1 percentage point in the logarithmic growth rate of card turnover leads to a decline of 0.3 percentage point in the logarithmic growth rate of real domestic demand for banknotes. The impact of the logarithmic growth rate of real cash consumption is, with a value of 0.55 (in absolute terms), almost twice as large. The positive sign is consistent with the theory.[33] A change in interest rates has, in accordance with the theory, a negative impact on the logarithmic growth rate of real domestic banknote circulation. The highly significant impact of the tax and social security contributions ratio on the logarithmic growth rate of real domestic demand for banknotes is, at half a percentage point (in absolute terms), exactly the same as the impact of interest rates and is considerably less than proportional. The adjusted R^2 value of 0.71 is satisfactory and the model passes all of the diagnostic tests.

The long-run multiplier of the shadow economy variable "tax and social security contributions ratio" in relation to the logarithmic growth rate of real domestic banknote circulation has a value of 0.022. This is to be interpreted as follows: if there is a sustained rise of 1 percentage point in the tax and social security contributions ratio, the logarithmic growth rate of real domestic circulation rises by around 2.2 percentage points over the long term.[34] In order to classify this result, it is helpful to take a look at the development of both time series. In the estimation period, the tax and social security contributions ratio fluctuated within a range from 20.3% to 24.4% (see *Figure 1*) and the logarithmic growth rate of real domestic circulation was within an interval of -3.5% to 5.3%. On balance, the long-run multiplier of the shadow economy variable "tax and social security contributions ratio" in relation to real domestic banknote circulation can therefore be considered economically significant.

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33 There are economies of scale in the holding of cash when the economic agents reduce their cash holdings in relation to their transactions (or income) with increasing transaction volume (or income). This is the case if the transaction elasticity or income elasticity of cash demand is less than 1; see Boeschoten (1992, pp. 23-24). The coefficient cited here (with a value of 0.55) represents a derivative of the logarithmic growth rate of real domestic banknote circulation based on the logarithmic growth rate of real cash consumption. This derivative does not correspond to transaction elasticity, which is defined as the quotient of these growth rates. On this basis, no conclusions regarding economies of scale in domestic cash demand can be drawn here.

34 It should be noted that the tax and social security contributions ratio is quoted in percentage points while the logarithmic growth rate of real domestic circulation is quoted as a percentage. If, for example, the latter rises from 0.01 or 1% to 0.032 or 3.2%, this constitutes a rise of 2.2 percentage points.

In addition to estimating the influence of the shadow economy on domestic banknote demand in the form of partial effects, i.e. by reference to regression coefficients, an attempt was made to determine the value of banknotes in domestic cirulation used for shadow economic purposes using a dynamic simulation. For this purpose, the shadow economy variable was set at zero in the entire estimation period in ARDL model (6) from *Table 3* and the resulting real domestic banknote circulation was simulated in terms of value. This was compared with the domestic banknote circulation estimated in regression model (6) in order to determine the contribution of tax evasion to domestic banknote circulation since the beginning of the estimation period, i.e. since the second quarter of 2003. No meaningful results could be obtained using this approach, however.

Finally, the dynamic regression model for domestic banknote circulation with the proxy variables “tax and social security contributions ratio” (model (6) in *Table 3*) is compared with the other empirical works on the relationship between currency demand and the shadow economy in Germany.[35] Unlike in the present study, previous estimates of the shadow economy in Germany using the currency demand approach have almost exclusively used measures of the tax burden as a proxy variable for the shadow economy.[36] One exception is Karmann (1990), who, in addition to using a measure of the tax burden (to estimate the supply side of the shadow economy), also uses a measure of the consumer burden through the prices of regular services (to estimate the demand side of the shadow economy). None of the

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35 No comparison of coefficients in the different models is undertaken here, given that such a comparison is only possible for nested models. Two models are nested if one model can be reduced to the other model by means of linear restrictions on parameters. This is not the case here. The coefficients of the common variables are often examined to see whether they are significant in both models and whether their value differs between the models. Such comparisons are erroneous for the following reasons. Firstly, they do not take into account that the coefficients in one model are not independent of those in the other model. Secondly, both models cannot be true at the same time, unless they are equivalent. In nested models, comparing the coefficients is equally challenging (Clogg et al.,1995, p. 1263). Clogg et al. (1995) show how nested models can be tested to see whether the coefficients of the common variables differ between the models.

36 See Kirchgässner (1983), Langfeldt (1989), and Pickhardt and Sardà (2006).

previous empirical works on the relationship between currency demand and the shadow economy in Germany take foreign demand into consideration. These studies all refer to the D-Mark era, a period in which foreign demand is already likely to have played an important role. In this vein, Seitz (1995), using various estimation approaches, comes to the conclusion that in the mid-1990s, 30% to 40% of the total volume of DM cash was in circulation outside Germany.

3 Summary and conclusions

This paper examines the role of shadow economic motives for the real demand for euro banknotes issued by the Bundesbank. In this context, regressions were estimated for the circulation of small, medium and large denominations respectively, as well as for domestic circulation.

The main focus of this analysis is on the long-term relationship between banknote demand and the shadow economy (illicit use of cash). It does not address the shadow economy as a whole, but rather its different forms. The latter are depicted using seven alternative proxy variables.[37] For banknote demand in its various definitions only one or two of the seven shadow economy variables examined here respectively play a role; see the summary of the regression analysis in *Table 4*. What stands out is the employment rate in the construction sector, which has a significant influence on the demand for both medium and large-denomination banknotes. Otherwise, the demand for small, medium and large-denomination

37 An indicator which represents the common factor of the proxy variables for the shadow economy can be used as a regressor for modelling the shadow economy as a whole. This is based on the assumption that there is no perfect measure of the shadow economy or that all such measures are subject to measurement errors. In this context, a distinction should be made between the production-orientated, stationary proxy variables for the shadow economy on the one hand and the non-stationary crime variables on the other. Alternatively, the shadow economy as a whole can be depicted by the simultaneous incorporation of all seven proxy variables for the shadow economy as regressors. Arguments against this method are the relatively low number of observations and potential problems owing to multicollinearity.

banknotes, as well as domestic demand for banknotes, each depend on different shadow economy variables. The self-employment rate is the only shadow economy variable which has no influence on the demand for banknotes. The shadow economic motives for banknote demand grow in significance as the denomination size increases. While the impact of the shadow economy on the demand for small denominations is low, its impact on the demand for large denominations is roughly as large as the short-term effect of the financial crisis at the end of 2008.

Long-term effects of the shadow economy on the value of banknotes in circulation

Table 4

Sustained rise in the proxy variable for the shadow economy	**Long-term effect on the real circulation of German-issued euro banknotes**
Unemployment rate increases by 1 percentage point	Growth rate of the circulation of small denominations increases by 0.7 percentage point***
Growth rate of the total number of crimes increases by 1 percentage point	Growth rate of the circulation of small denominations increases by 0.7 percentage point***
Number of drug-related crimes increases by 1%	Circulation of medium denominations increases by 1.1%***
Employment rate in the construction sector increases by 1 percentage point	Growth rate of the circulation of medium denominations increases by 3.3 percentage points**
Employment rate in the agricultural sector increases by 1 percentage point	Growth rate of the circulation of large denominations increases by 12 percentage points***
Employment rate in the construction sector increases by 1 percentage point	Growth rate of the circulation of large denominations increases by 9 percentage points***
Tax and social security contributions ratio increases by 1 percentage point	Growth rate of domestic circulation increases by 2.2 percentage points**

Notes: *** statistically significant at 1%, ** statistically significant at 5%. All of the long-term effects are economically significant. Small denominations: €5-€20 banknotes, medium denominations: €50 and €100 banknotes, large denominations: €200 and €500 banknotes.
Source: Authors’ own calculations.

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Walter Engert, Ben S. C. Fung, Björn Segendorf

A Tale of Two Countries: Cash Demand in Canada and Sweden[1]

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Abstract

Cash is being used less and less for making payments in many countries, including Canada and Sweden, which might suggest that cash will eventually disappear. However, cash in circulation in most countries, including Canada, has been stable for decades, and even rising in recent years. In contrast, aggregate cash demand in Sweden has been falling steadily. This paper explains these differences between Canada and Sweden by focusing separately on the transactions demand for cash and on the store-of-value demand. We find a long-term downward trend in small-denomination bank notes relative to gross domestic product in both Canada and Sweden. This reflects similar experiences in decreasing cash use for trans-

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actions over time due to the adoption of payment innovations. This means that payment innovations and diffusion are not sufficient to explain why aggregate cash demand has been declining rapidly in Sweden but not in Canada. Instead, the difference in the trends of cash demand between these two countries is due more to the behaviour of larger-denomination, store-of-value bank notes. Finally, we identify influences and frictions that help explain the persistent decline in the demand for larger bank notes in Sweden relative to Canada.

1. Introduction

Cash is being used less and less for making payments in many countries, including Canada and Sweden.[2] *Figure 1a* and *1b* show that the number and the value of cash transactions have been declining over the last two decades in both of these countries.[3] One of the main reasons for declining cash use has been the growing reliance on electronic payment methods, such as credit and debit cards.[4] *Figures 2a* and *2b* present the value of cash, debit card and credit card spending relative to gross domestic product (GDP) in Canada and Sweden. Canadians have long preferred to use credit cards, and their use of debit cards also overtook cash in the early 2000s (*Figure 2a*). In comparison, while Swedes were still using cash more than cards in 2001, they have increasingly preferred debit cards to make purchases since the early 2000s, and in the last few years credit card use has also overtaken cash (*Figure 2b*). Corresponding to these trends, increasing card acceptance by merchants has also contributed to greater card use in both Canada and Sweden.

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2 The terms cash and bank notes are used interchangeably in this paper.

3 The value and number of cash payments are estimated using cash withdrawal data from automated teller machines (ATMs). For a discussion of the methodology and limitation of the estimation, see Arango et al. (2012).

4 For a discussion of these developments in Canada, see, e.g., Fung, Huynh and Stuber (2015) and Henry, Huynh and Welte (2018). For Sweden, see Segendorf and Wretman (2015) and Sveriges Riksbank (2013).

Such persistent declines in cash use in numerous countries might suggest that cash will eventually disappear. Indeed, *Figure 3a* illustrates that cash demand more generally (the ratio of cash to GDP) steadily decreased in a number of countries following the end of the Second World War.[5] However, the cash-to-GDP ratio stabilized in most countries in the late 1970s and early 1980s. In Canada, for example, bank notes as a ratio of GDP declined steadily from 10 percent in 1946 but then stabilized in the 1980s and have remained between 3 and 4 percent. There has even been a slight upward trend after the 2008 financial crisis in Canada and in most other advanced economies (Bech et al. 2018). So, decreasing cash use for transactions has not resulted in a sustained decline in cash demand in Canada (to this point). And the story is similar in most other advanced economies (*Figure 3a*).

The evolution of cash demand in Sweden and Norway, however, has been markedly different from the experiences of other advanced countries (*Figure 3b*). In Sweden, for example, the value of bank notes relative to GDP declined continuously from a peak of 13.5 percent in 1945 to 1.2 percent in 2017. Unlike the experience in most other advanced economies, cash-to-GDP did not stabilize in the 1980s, nor did it increase after the financial crisis. Moreover, the absolute value of bank notes outstanding in Sweden started to decline in 2007, from a peak of SEK 108.5 billion in 2007 to just over SEK 55 billion in 2017. Thus, in Sweden, declining cash use for payments appears to be more closely associated with the decrease in cash demand more generally. Indeed, the popular press has been predicting that Sweden will become the world's first cashless society when the Swedes stop using cash completely.[6]

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5 The ratio of cash in circulation to GDP is widely used as a measure of the demand for cash and thus the importance of cash in an economy. The value of cash in circulation, like other goods, is determined by both supply-side factors (e.g. the number of bank branches and the size of the ATM network) and demand-side factors (e.g. the use of cash for payments and as a store of value). In most countries, including Canada and Sweden, the central bank typically provides enough cash to meet the demand for cash; thus, the value of cash in circulation reflects the underlying demand for cash.

6 See, e.g., N. Heller, "Imagining a Cashless World," The New Yorker, October 3, 2016.

The divergent experiences of Canada (and other advanced countries) on the one hand and Sweden (and Norway) on the other raise several questions. Why has there been a persistent decline in overall cash demand in Sweden but not in Canada? Have Swedes been reducing cash use more quickly than Canadians? Are there meaningful differences in payment innovations in the two countries that can explain these experiences? Are there large differences in the availability and supply of cash? What factors could explain the different trends in cash demand more generally in the two countries? Does Sweden's experience of continuously falling cash demand indicate the future for other advanced economies, such as Canada?

This paper studies both the use of cash and the demand for cash in Canada and Sweden and analyzes the main factors affecting cash use and demand in these two countries. More specifically, we discuss supply side factors such as the bank note distribution system and the access of cash through ATMs and bank branches, as well as demand side factors such as consumers' use of cash and merchants' acceptance of cash for transactions, and the holding of cash as store of value. We also discuss foreign demand and the demand for cash in the underground economy. In addition, we identify some unique developments in Sweden that help explain the persistent decline in the demand for bank notes. Such analysis can inform our understanding of potential turning points for cash demand in Canada, as well as policy measures that might affect such outcomes.

The Riksbank has been studying the implications of a persistent decline in cash use and demand in Sweden, highlighting some potential difficulties from a cashless society.[7] Engert, Fung and Hendry (2018) also study the implications of a cashless society and note areas that could raise some concerns in that context–that is, operational reliability and contestability in retail payments, and the availability of a safe store of value in an extreme financial crisis. They also suggest options for policy-makers

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7 See, e.g., Sveriges Riksbank (2017) and Sveriges Riksbank (2018a).

to deal with these potential problems, including taking steps to inhibit declining cash demand, regulating retail payment systems and issuing a central bank digital currency (CBDC) in a cashless society. To assess policy responses, it is important to understand the factors that could lead to the disappearance of cash in an economy. In particular, policy-makers might want to know how to avoid or inhibit declining cash demand. If this is not possible or desirable, then the central bank and other public authorities would need to consider other policy options to mitigate concerns if a cashless society were to evolve (as noted in Engert, Fung and Hendry 2018).

Canada and Sweden are similar in many ways. For instance, both of these northern countries are small, open economies that neighbour on much larger economies (the United States and those in the euro zone, respectively). Each has its own national currency, while citizens have easy access to an international reserve currency (the US dollar and the euro). The macroeconomic environments in Canada and Sweden also share similarities. For example, both Canada and Sweden have monetary policy frameworks that target inflation, and both have pursued the same inflation-control objective (2 percent) since the beginning of the 1990s. Their banking systems are broadly similar, each dominated by a handful of large, universal banks, but also including many smaller institutions. Canada and Sweden also both rank high in terms of digital infrastructure relevant to cashless payments; both are seen as among the most significant adopters of cashless payment methods and both are considered among the most cashless societies in the world.[8] Finally, each has experienced a range of payment innovations over the past few decades (e.g., Swish in Sweden, and Interac e-Transfer in Canada) that have contributed to the reduced use of cash for payments.

8 For rankings of digital infrastructure and network readiness, see the Networked Readiness Index compiled by the World Economic Forum). For an example of rankings of cashless societies, see, S. Smith, "The 10 Most Cashless Countries in the World: Where Does the UK Rank?" The Telegraph, October 10, 2017,.

And yet, despite the similarities, the evolution of overall cash demand is very different in the two countries, as shown above. It follows then that studying the factors driving cash demand in Canada and Sweden could inform our understanding of the importance of various influences and provide some insight into the evolution of cash demand in Canada: Will cash demand in Canada follow Sweden's path?

The rest of the paper is organized as follows. The next section discusses access to cash in Canada and Sweden, focusing on how bank notes are distributed to the general public. The following two sections consider transactional and non-transactional demand for cash. More specifically, the third section discusses the main factors that determine transactional demand and assesses whether these can explain the differences between cash demand in Canada and Sweden. Section 4 considers non-transactional demand for cash and related influences. Section 5 discusses the use of cash in the underground economy. The final section provides conclusions.

2. Access to cash in Canada and Sweden

Typically, a central bank distributes bank notes to financial institutions; these, in turn, operate a network of branches and automated teller machines (ATMs) that allow the public to withdraw or deposit bank notes. This section begins with a brief overview of the banking systems in Canada and Sweden and then describes how the respective central banks distribute bank notes to financial institutions. Access to cash by the general public through financial institutions' branches and ATMs is also considered. We discuss differences between Canada and Sweden regarding providing and accessing cash, and whether this affects cash use and demand.

2.1 Overview of the Swedish and Canadian banking systems

In Canada, six major universal banks dominate financial services.[9] These six banks account for over 90 percent of total banking assets and have a significant economic footprint, with assets around 2.5 times Canadian GDP. The major Canadian banks are also highly interconnected with each other and with the broader financial system. They also play important roles in most aspects of the Canadian financial system (OSFI 2019). These banks are well-diversified. Each provides a wide range of financial services across Canada, with commercial and personal (including mortgage lending) segments comprising the core businesses (IMF 2014). The largest four Canadian banks have an important presence outside of Canada as well, variously in the United States, the United Kingdom and South America. In addition, each of the major banks in Canada has been designated as a domestic systemically important bank, subject to enhanced regulatory provisions and a specific, open-bank (bail-in) resolution regime. One of these banks–Royal Bank of Canada–has also been designated a global systemically important bank by the Financial Stability Board (FSB). There is also a large number of smaller banks–about 80–along with many trust and loan companies, and co-operative deposit-taking institutions that are particularly important in certain regions of the country.

Similar to the Canadian case, four major, universal banks dominate financial services in Sweden.[10] These four banks account for about 85 percent of total banking assets and two-thirds of broader financial system assets more generally (IMF 2017). The major banks' assets are large compared with the Swedish economy, amounting to around 5.5 times Swedish GDP. These banks are also highly interconnected with each other and with other participants in the financial system. Further, they play important roles in most aspects of the Swedish financial system. Each of the

9 These six banks are Bank of Montreal, Banque Nationale, Canadian Imperial Bank of Commerce, Royal Bank of Canada, Scotiabank and TD Bank.

10 These four banks are Handelsbanken, Nordea, SEB (Skandinaviska Enskilda Banken) and Swedbank. In October 2018, Nordea moved its head office (and legal incorporation) from Sweden to Finland.

four major banking groups provides a wide range of financial services, but they have somewhat different business mixes and geographic concentrations across the Nordic and Baltic regions and other countries (IMF 2017). Nevertheless, the commercial banks and their mortgage subsidiaries are the dominant entities for each major bank. Nine financial institutions have been designated by Swedish authorities as domestic systemically important (Riksgalden 2018a) and are therefore subject to enhanced regulatory provisions and a specific, open-bank bail-in resolution regime. One of the major banks operating in Sweden–Nordea–has also been designated as a global systemically important bank by the FSB. In addition to the four dominant Swedish banks, there are also many–over 100–smaller banks, including niche participants and some foreign bank subsidiaries and branches (Swedish Bankers' Association 2018).

With low interest rates and interest-spread compression prevailing in the last 10 years, the major Canadian and Swedish banks have sustained profits with low credit losses, an expansion of real-estate-based lending (mortgages) and increased fee income, along with tight control of operating expenses (Finansinspektion 2018; IMF 2017).

In sum, the banking market structures in Canada and Sweden are broadly similar, characterized by the dominance of a handful of large, universal and systemically important banks, but with many smaller institutions competing as well. Further, the strategic, business responses of the major banks in each country to the prevailing economic influences in recent years have been broadly similar.

A key difference between Canadian and Swedish banks concerns their funding. The major Canadian banks rely on personal and other deposits, which provide for over half of their liabilities, almost equally split between demand/notice deposits and fixed-term deposits (IMF 2014). And Canadian-dollar personal deposit funding is about 35 percent of Canadian-dollar assets. In contrast, the major Swedish banks depend on wholesale, market funding, primarily through covered bonds.

Correspondingly, deposits comprise only about one-third of the aggregate funding for Swedish deposit-taking institutions (IMF 2017). Similarly, SEK personal deposits amount to just 17 percent of SEK assets.

2.2 Bank note distribution systems

The Bank of Canada is the sole issuer of bank notes in Canada and is responsible for providing adequate bank notes in circulation to meet the public's demand. In 1998, the Bank of Canada introduced a computerized inventory-management system, the Bank Note Distribution System (BNDS), to facilitate the exchange of bank notes between the Bank and participating financial institutions, and between financial institutions themselves.[11] Through two agency operation centres (AOCs) in Toronto and Montreal, the Bank of Canada exchanges bank notes with 43 regional distribution centres (RDCs) located in 10 regional distribution points (RDPs) across the country.[12] Each RDC is owned by one of the nine financial institutions that are members of the BNDS (which include most of the major Canadian banks), and each member financial institution is allowed to have no more than one RDC in each RDP. A financial institution's RDC manages the note flows of its regional network of branches and ATMs.

A member financial institution with surplus notes declares them to the BNDS, receives credit from the Bank of Canada, and then moves them to the vault of its RDC, segregated from its own note holdings. A financial institution that needs notes places orders on the BNDS and arranges for the transportation of notes from other RDCs in the same RDP that have surplus notes. The Bank then debits its accounts accordingly. Unfit notes are shipped by financial institution branches to their RDCs, where the notes are registered as deposits to the Bank. These notes are then shipped by the Bank to one of its AOCs for processing and removal from circulation. The Bank

11 Bilkes (1997) provides background information and an overview of the system.
12 These regional distribution points broadly correspond to the different provinces of Canada.

also supplies new notes (and processed fit notes) as needed by shipping these notes to the RDCs, where they are held in the vaults of the RDCs until required.

In Sweden, the Riksbank started issuing bank notes early in the 18th century. The number of Riksbank branches at which banks can obtain cash from the Riksbank has been declining gradually in recent decades. In the late 1980s, the Riksbank had 20 local branches that managed note distribution, and by 2006 this number had declined to two. Since 2014, only one Riksbank regional branch remains in operation. Consequently, the network of cash distribution depots is now mostly operated by the market.[13] Banks bear costs from cash in terms of foregone interest, which generates an incentive for the banks to deposit cash at the Riksbank each afternoon and withdraw cash the next morning to cover the day's needs. To avoid unnecessary transportation and related costs, banks are credited interest compensation if they store and report idle cash at the depots in accordance with a specific set of requirements.

In sum, both the Bank of Canada and the Riksbank have substantially decentralized note processing, storage and distribution to financial institutions. As a result, financial institutions bear a significant share of the costs of providing cash to the public. In Canada, for example, Kosse et al. (2017) estimate that 56 percent of the total resource costs of cash are borne by financial institutions. Similarly, Segendorf and Jansson (2012) estimate that banks and cash-in-transit companies bear about half of the total resource costs of cash (and nearly all of the cash distribution costs specifically). Therefore, financial institutions in both countries are constantly looking for ways to reduce the costs related to their cash operations.

13 Similar to the Canadian experience, the transition in Sweden to rely on market participants to distribute cash was motivated by the Riksbank's view that the market is better suited to providing efficient cash distribution than is the central bank itself. See Daltung and Ericson (2004) for more background on this decision.

2.3 Access to cash through ATMs

To obtain cash for transactions, consumers usually rely on ATMs. This is facilitated by the high degree of access to banking services in both Canada and Sweden, as virtually all Canadians and Swedes have a bank account.[14] In Canada, ATMs handle mainly $20 and $50 notes, and some bank ATMs recently began dispensing $100 notes as well. Some also provide customers with choice across a range of note denominations. Canadian bank ATMs typically accept deposits of bank notes and cheques as well. In Sweden, ATMs generally handle 100-krona , 200-krona notes (since 2015), and 500-krona notes (which some ATMs started dispensing in the late 1980s), but not the smallest denominations, 20-krona and 50-krona notes.[15] ATMs have withdrawal limits in both countries, set by each bank.

Figure 4a shows that the number of ATMs per million population in Canada is much higher than in Sweden; more specifically, there are about 10 times more ATMs per million inhabitants in Canada than in Sweden. Further, the number of ATMs in Canada had been growing until recently, with much of this increase coming from white-label ATMs. The number of ATMs in Sweden has been fairly stable over the last 20 years. In Sweden, the distribution of ATMs has recently started to move away from bank branch locations toward "cash centres" that congregate several ATMS in high-traffic areas, such as shopping malls.[16] Major Canadian institutions also place ATMs in high-traffic areas, as well as in bank branches.

While there are many more ATMs per capita in Canada than in Sweden, this does not necessarily mean that there is a friction inhibiting access to transactional cash in Sweden compared with Canada. The business models underlying the deploy-

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14 More specifically, over 99 percent of Canadians and 97 percent of Swedes have a bank account according to the latest survey data; for Canada, see Henry, Huynh and Welte (2018), and for Sweden, Sveriges Riksbank (2018b).

15 The CAD/SEK exchange rate is about 1:7 (July 2019).

16 In 2017 there were about 100 such cash centres, and 30 more were expected to open in 2018. See Bankomat press release, May 17, 2018.

ment of ATMs in the two countries appear to be quite different. In Canada, banks apparently see their ATM networks as part of their branding and a means to attract and retain customers. Major Canadian banks each have their own branded ATMs to compete for customers, joined in a common network linking all banks' ATMs. As a result, customers can withdraw cash from their own-bank ATMs with no (or minimal) charges. They can also withdraw funds from their account via another bank's ATMs or white-label ATMs, but subject to additional fees for most account holders. And bank customers can deposit cash (and cheques) only at ATMs of their own bank.

In comparison, Swedish banks appear to have viewed ATMs more as a cost centre than a means of competition, and thus have collaborated since the late 1960s to work toward shared and interoperable bank-ATM networks to reduce their costs. By the mid-1990s, bank and savings bank ATM networks were interoperable to provide for cash withdrawals (but not deposits) across all ATMs. In 2013, all bank ATMs in Sweden came under the management of one company, to improve interoperability and service more generally.[17] As a result, customers of any Swedish bank can use any ATM to access their account to withdraw cash without being subject to any fees. This suggests that a smaller ATM network would be sufficient to provide for cash distribution (other things equal). In this context, Swedish banks have also been concerned about possible adverse impact of a common, generic ATM network on their branding. This has been addressed by having the ATM display the specific card-issuer's starting page following recognition of the customer's inserted access card.[18] However, Swedish ATMs do not generally accept cash

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17 The Swedish ATM network is currently managed by Bankomat AB, which is jointly owned by the five largest banks in Sweden: Danske Bank, Handelsbanken, Nordea, SEB, Swedbank (with the Savings Banks) For more information, see Bankomat website. The tradition of co-operation among Swedish banks in this regard is described in Segendorf and Wretman (2015). See also Bátiz-Lazo (2018), especially *Table 6.2*.

18 In addition to the dominant ATM network, one bank has kept its own ATM network, and there are some white-label ATMs as well. Further, ICA (the largest grocery store chain in Sweden) opened ICA Bank, which has an (in-store) ATM network that is interoperable with the main ATM network. One of the cash-in-transit companies also operates its own ATM network. These two networks each have nearly 20 percent of the market.

deposits, and specific cash-deposit machines have been hard to find. As a result, depositing cash was becoming increasingly difficult in Sweden (more on this below).[19] Recently, however, cash-deposit machines are being located at cash centres (noted above) along with regular ATMs.

In sum, different competitive and business strategies seem to explain the much smaller number of ATMs per capita in Sweden than in Canada. But the nature of the interoperability of the bank ATM networks in Sweden suggests that this is unlikely a material friction in accessing transactional cash via ATMs. A recent official study (Statens offentliga utredningar 2018) on access to cash in Sweden reached a similar conclusion, but raised questions about access to deposit services, especially given the development of cashless bank branches in Sweden (discussed below).

2.4 Access to cash through bank branches

Larger bank notes are usually not available in ATMs and, instead, are supplied via bank branches in both Canada and Sweden. Therefore, the ease of accessing cash services from banks influences the use and holding of larger notes in these two countries. *Figure 4b* shows that the number of bank branches per million population is much higher in Canada than in Sweden; that is, there are about 50 percent more branches per million inhabitants in Canada.[20] This suggests that accessing cash through bank branches is more difficult in Sweden than in Canada. The number of bank branches per million population, however, has been declining in both countries, especially since the 2008 financial crisis.[21]

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19 A search of Bankomat's website reveals that few of its ATM locations provide cash deposit services.
20 The data for Canada include branches of banks, credit unions and governmental savings institutions; for Sweden, branches of banks and savings banks are included. All data are from the BIS Redbook.
21 A subsidiary of the Swedish Post—Svensk Kassaservice—had provided basic cash and payment services over the counter, but it was closed in 2008. For more on this, see Statens offentliga utredningar (2018).

Further, it has become increasingly difficult to access cash in a bank branch in Sweden since many bank branches no longer provide over-the-counter (teller) cash services. These cashless branches might provide cash withdrawal services via ATMs located in the branch, but given the strategy to build ATM cash centres, bank branches with ATMs are becoming increasingly unusual in Sweden. This development is considered further in Section 4, which focuses on various influences affecting the demand for larger-denomination notes.

2.5 Summing up

A number of key factors influencing access to cash in Canada and Sweden are similar, including banking market structures and the bank note distribution systems. While there are significantly fewer ATMs per capita in Sweden, the nature of the interoperability of the ATM networks in Sweden suggests that this is unlikely related to any material friction around accessing transactional cash via ATMs.[22] However, a relative lack of access to deposit services at ATMs, fewer bank branches per capita and the development of cashless bank branches in Sweden could represent frictions that inhibit the demand for cash (particularly for larger value bank notes) compared with in Canada. These aspects are discussed further below.

3. Small-denomination bank notes and transactional demand for cash

As discussed above, cash-to-GDP in Canada and Sweden trended down for years after the end of the Second World War. But while the cash-to-GDP ratio stabilized in Canada in the early 1980s and has even increased somewhat in the last few years, this ratio has continued to fall steadily in Sweden. As a result, cash-to-GDP in Sweden fell below that of Canada in 2009 (although Sweden has had a higher

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22 Taken together, the number of cash-withdrawal points in Sweden (ATMs, bank branches and various shops) decreased by 38 percent between 2011 and 2018 (from 5,232 to 3,212; Länsstyrelserna 2018).

ratio for most of the post-war period). Considering small- and large-denomination notes separately illuminates these contrasting trends.

Figures 5a and *5b* plot the ratio of small-denomination notes-to-GDP and large-denomination notes-to-GDP separately. For Canada, notes of less than $50 in value are considered small-denomination notes, and notes of $50 or more are considered large-denomination bank notes. For Sweden, notes less than 500 krona are small-denomination notes, and the 500-, 1,000- and 10,000-krona notes (which were removed from circulation in 1993) are considered large-denomination bank notes.[23]

For small denominations, the patterns are similar in Canada and Sweden, with the ratio of small notes to GDP in both countries following a long-term declining trend.[24] This ratio was generally higher in Sweden than in Canada for most of the immediate post-war period (e.g., in 1946, 10.6 percent in Sweden versus 7.4 percent in Canada), suggesting that Sweden was more cash-intensive than Canada during these decades. However, the value of small notes to GDP has declined substantially in both countries since 1946, and since 1988 this ratio has been lower in Sweden than in Canada. In 2018, it reached 0.3 percent in Sweden and 1 percent in Canada.

For large denominations, however, the trends in the two countries have been strikingly different. In Canada, the value of large notes-to-GDP declined from the late

23 This classification is consistent with the literature, which typically considers the largest two or three denomination bank notes as "large-denomination" notes. See, e.g., Amromin and Chkravorti (2009) and Judson (2018). For a long-time series, however, there are some caveats. Persistent inflation, e.g., could suggest that some notes, especially $50 and 500-krona notes, should not be considered to be "large denomination" (primarily store-of-value) notes throughout the entire period under consideration. That is, with a rising price level, such notes become more suitable for making payments over time. This perspective is reinforced by fact that these particular notes ($50 and 500-krona) have become available in ATMs in Canada and in Sweden, respectively.

24 It should be noted that small-denomination notes relative to GDP are also declining in many other advanced economies; see, e.g., Judson (2018).

1940s, stabilized in the late 1960s and has been rising since the early 1980s. Further, the rate of increase has accelerated since the 2008 financial crisis. In Sweden, large notes to GDP increased slightly from the late 1940s, and this increase accelerated in the 1970s. The ratio of large notes to GDP then stabilized in the early 1990s before going into a persistent downward trend starting in 2001.

Figures 5a and *5b* show that the decline in small denominations was driving the downward trend in total cash demand in Canada until the 1980s, and in Sweden until the mid-1990s. After 1980 in Canada, rising demand for large denominations offset declining demand for small denominations, resulting in fairly steady total cash demand and a slight upward trend after the 2008 financial crisis. After 1995 in Sweden, total cash demand briefly stabilized (at around 4 percent), as demand for large denominations remained at a high level while demand for small denominations continued to decline slowly. In 2001, the demand for large denominations started to fall, driving the sharp downward trend in total cash demand for the last two decades in Sweden.

Small-denomination notes are typically used for transactions, especially for day-to-day purchases, as these notes are widely accepted by merchants and are readily available at ATMs. While large-denomination notes are also used for transactions, such notes are more likely held as a store of value.[25] The cash-to-GDP ratios in *Figures 5a* and *5b* suggest that cash held for transactions (small notes) has been consistently declining since the 1940s in both Canada and Sweden. In contrast, cash held for non-transactional reasons (large notes) has been following different trends in Canada and Sweden over the last three decades–and so are the key to explaining the difference in total cash demand over time in Canada and Sweden.
Indeed, these divergent trends suggest that it is useful to consider separately the factors that have influenced holdings of small denomination notes and large de-

25 See Amromin and Chkravorti (2009).

nomination notes. Accordingly, the rest of this section focuses on influences affecting the demand for small-denomination notes in Canada and Sweden. Section 4 then considers the demand for large-denomination notes, where there appear to have been some notable differences between the two countries.

3.1 Cash for point-of-sale transactions

As discussed above, increased use of electronic payment methods such as debit cards and credit cards has led to reduced use of cash. Card ownership is very high in Canada, with 99 percent of Canadians owning debit cards and 89 percent owning credit cards (Henry, Huynh and Welte, 2018). In Sweden, 97 percent of the population has a debit card but only 49 percent owns a credit card (Sveriges Riksbank, 2016). Correspondingly, the use of cash for payments has been decreasing relative to cards in both Canada and Sweden (*Figures 2a* and *2b*).

While cash is still the single most popular payment method for small-value transactions in Canada (i.e., less than CAD 15), retail payment innovations such as contactless cards are also reducing the use of cash for such transactions (*Figure 6a*). In Canada, the cash-value share of transactions less than CAD 15 has declined from 65 percent in 2009 to just 40 percent in 2017, while the value share of contactless credit cards has grown considerably. In Sweden, while 20 percent of the population in 2018 still prefer cash for transactions that are less than SEK 100 (which is around CAD 15), more than 70 percent consider debit cards to be their main payment method for all transaction sizes as shown in *Figure 6b* (Sveriges Riksbank, 2018).

Contactless credit cards and contactless debit cards were introduced in Canada in 2011, and their use has grown rapidly (*Figure 6a*). Survey data suggest that contactless cards are particularly popular for transactions less than CAD 15.[26] Currently,

26 See also Henry, Huynh and Welte (2018), Chart 3. Note that contactless credit cards and debit cards in Canada have a limit on the size of the transaction, set by the issuing bank, typically at CAD 100.

all credit cards and most debit cards in Canada support the contactless function, and an increasing number of payment terminals are contactless-ready. As a result, contactless cards will likely continue to have a significant and growing impact, reducing cash use for transactions in Canada.[27] And this impact could be especially notable for small-value transactions, where cash has been a relatively popular payment method, given the speed and convenience of using contactless cards.

In Sweden, contactless cards began to roll out only in 2016 and have been gradually gaining popularity. All cards and 94 percent of payment terminals are expected to support the contactless function by the end of 2019 and, as in Canada, contactless cards are likely to lead to a continuing decrease in cash use for transactions in Sweden.[28]

Another common gauge of cash use is the number of consumers who report using cash for transactions over some prior period. In this regard, survey data in both Canada and Sweden (somewhat differently configured) indicate that declining proportions of their populations are using cash. Surveys conducted in Canada show that the percentage of Canadians who have used cash in the past week is declining, from 88 percent in 2010 to 68 percent in 2017.[29] At the same time, however, preliminary results from a subsequent survey suggest that only a small proportion (7 percent) of consumers have stopped using cash entirely, and only 5 percent plan to abandon cash in the next five years (Bitcoin survey 2018). Similarly, according to the Riksbank, the percentage of Swedes using cash in the past month declined from 94 percent in 2010 to 61 percent in 2018. So, while cash use has been declin-

27 Fung, Huynh and Sabetti (2014) and Chen, Felt and Huynh (2017) show that introducing retail payment innovations, such as stored-value cards and contactless credit cards, leads to a reduction in cash usage for transactions in terms of both value and volume. (Additional work is underway at the Bank of Canada on the impact of recent innovations such as contactless cards and person-to-person payment methods on cash use.)

28 For more information on contactless payments in Sweden, see the Contactless Forum website.

29 Canadian Financial Monitor conducted by Ipsos Reid.

ing in both Canada and Sweden, it seems likely that some cash use for payments will continue for (at least) the medium term.

A payments market is a two-sided market, as consumers and merchants influence each other in the use and acceptance of various payment methods. Fung, Huynh and Kosse (2017) argue that it is consumers, however, who ultimately determine the prevalence of a payment method. Therefore, as long as a sufficient number of consumers use cash, merchants are likely to continue to accept it for transactions. However, if cash use continues to decrease such that eventually only a small number of consumers use cash, merchants might reconsider their acceptance of cash given the costs associated with it. Merchant acceptance of cash is discussed further below.

3.2 Cash for person-to-person transactions

Cash has long been the main payment method for person-to-person (P2P) transactions in a number of countries (see, e.g., Fung, Huynh and Stuber 2015). But innovations in P2P payments, such as Interac e-Transfer in Canada and Swish in Sweden, have the potential to reduce considerably the use of cash for P2P transactions in both countries.

Interac e-Transfer is a P2P payment system in Canada that has been operational since 2001.[30] (e-Transfer can also be used for person-to-business, business-to-business and business-to-person transactions.) To make an e-Transfer payment, payers must log into their online or mobile banking service to initiate the process. Interac e-Transfer payment messages are exchanged between financial institutions through a secure network. When payers authorize a transaction, funds are immediately debited from their accounts and an email or text message to a mobile

30 Interac is the Canadian company that operates a debit payment network linking Canadian financial service providers.

phone is sent to the recipient. In principle, it can take up to 30 minutes for an e-Transfer to be received by its recipient, although in practice receipt occurs much more quickly for most transactions. For example, according to the website of a major Canadian bank, an Interac e-Transfer is typically received within one minute. Before 2017, recipients had to log into their bank's online or mobile banking service, select the account and answer a security question (posed by the payer) before the funds were credited to their account; but since 2017, customers can register to receive funds directly into a designated account without these above steps.[31] Financial institutions generally set daily, weekly and monthly sending and receiving limits for end-users as an important means of controlling fraud risk. Some banks also charge a fee for sending an e-Transfer, but receiving e-Transfers is always free of charge.

The left-hand panel of *Figure 7* shows that the number and value of Interac transactions have been increasing rapidly since 2011, at an annual rate of almost 50 percent. There are 15 million unique active users of Interac e-Transfer every month, and 80 percent of online banking customers are registered to use the e-Transfer service.[32] In 2018, consumers and businesses made more than 371 million transactions worth more than CAD 132 billion, with average transaction value of CAD 357. According to the 2017 MOP Survey, 57 percent of Canadians used Interac e-Transfer at least once in the preceding year.[33] While e-Transfer was designed initially as mainly an alternative to cash or cheque for P2P payments, in 2017, about one in six e-Transfer transactions are conducted by a business, and this segment is expected to grow in the coming years.

31 And at least one of the major banks now offers Interac e-Transfers via voice commands and Touch ID on its banking app.
32 For more on this, see Interac press release, "Use of Interac e-Transfer Service Surges in 2018." February 19, 2019.
33 See Henry, Huynh and Welte (2018), *Table 12*.

Swish is a P2P fast-payment system in Sweden that started operating in 2012. It was created by a consortium of Swedish financial institutions and is designed for use with smartphones. Every subscriber to Swish links a mobile phone number to a bank account.[34] A payer in Swish enters the payee's mobile number and authorizes the payment with the Swish app. Both the payer and payee receive notification through the Swish app in the course of the payment process, and only one or two seconds elapse between payment initiation and the availability of funds to the payee. Financial institutions typically impose a maximum transaction limit of around SEK 20,000.

According to a 2018 Riksbank payments survey, 62 percent of the Swedish population used Swish in the month preceding the survey. (This compares with 61 percent of survey respondents who reported using cash in the past month.) But only a small number of respondents reported using Swish to pay for their last purchase; this probably reflects the fact that the expansion of Swish to person-to-business payments and point-of-sale transactions is still at an early stage. (The point-of-sale service builds on QR-codes and has different levels of integration with the cashier system to target a broad range of businesses.)

The right-hand panel of *Figure 7* shows that use of Swish grew slowly in the first three years following its introduction in 2012. Starting in 2015, however, the number and value of Swish transactions increased sharply each year. According to Swish, by December 2018, nearly 6.8 million private individuals were using this system, which is about two-thirds of the Swedish population.[35] Furthermore, during December 2018, individuals made 29 million P2P transactions worth SEK 17 billion, with an average transaction value of about SEK 572. Almost 3,500 stores accepted Swish for payments in December 2018, where consumers made 6.3 million Swish

34 Businesses and charities generally obtain a proxy number to substitute for a mobile phone number.
35 Statistics on Swish were retrieved from the Swish website.

payments worth SEK 1.4 billion, with an average transaction value of SEK 227. In terms of total transacted value, Swish overtook cash in 2017.

3.3 Merchant acceptance of cash and cards

In Canada, cash is nearly universally accepted as a means of payment, according to a merchant survey conducted by the Bank of Canada (Fung, Huynh and Kosse 2017).[36] As for other means of payment, in 2014, almost all large businesses (i.e., those with more than 50 employees and more than one location) accepted payment cards, but only two-thirds of small and medium-sized businesses accepted cards. And about 5 percent of these businesses accepted only cash.

In Sweden, cash is also nearly universally accepted as a means of payment. More specifically, according to Arvidsson, Hedman and Segendorf (2018), whose work is based on a survey of Swedish retailers, 97 percent of merchants accepted cash at the end of 2016, about the same as the card acceptance rate. However, looking ahead, 25 percent of merchants reported that they expect to stop accepting cash by 2020, and over 50 percent expect to do so by 2025.[37] In this regard, the cost of handling cash, given decreasing cash turnover, is an important driver of potentially lower merchant acceptance of cash. Concern for the working conditions of employees, including security and allergic reactions to metal coins, is also an influence according to this survey. But retailers also expressed concern about the potential impact on customer satisfaction and sales of not accepting cash. (Swedish retailers indicated that a recommendation to discontinue cash acceptance from a relevant

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36 Preliminary results from a recent Bank of Canada merchant acceptance survey of cash by Huynh, Nicholls, and Nicholson (forthcoming) suggest that, among small and medium size businesses (less than 50 employees and $10 million in revenue), about 4 percent of merchants currently do not accept cash. Only about 8 percent of merchants plan to stop accepting cash in the next five years, while 79 percent of merchants do not plan to stop accepting cash and 8 percent are uncertain.

37 The fact that many merchants indicated they were planning to stop accepting cash in coming years seems consistent with recent anecdotal evidence that it is becoming more difficult to find stores in Sweden that accept cash.

organization, such as the retailers' association, or from a government authority would carry great weight in their eventual decisions.)

As noted, Swedish merchants report a greater interest than Canadian merchants in moving toward not accepting cash as a means of payment in the future. This difference might be partly explained by the different card payment schemes that consumers have been adopting in these two countries. As discussed above, in Sweden, consumers have been moving away from cash and toward debit cards for P2B payments, while in Canada, consumers have been moving toward mostly credit cards for P2B payments (Erlandsson and Guibourg, 2018; Henry, Huynh and Welte 2018). Given that debit cards tend to be less expensive for merchants than credit cards are (due to, e.g., lower interchange fees on debit cards), it is perhaps not surprising that merchants in Sweden report a greater willingness to move away from cash acceptance than merchants in Canada.[38]

The development of payment card readers that can be attached to mobile devices, such as Square in Canada and iZettle in Sweden, are also likely to lead to increasing merchant card acceptance. In particular, these devices allow merchants without regular store fronts and associated payment infrastructure, (e.g., pop-up stores, kiosks at festivals, craft and farmers' markets) to accept payment cards through mobile phones. (There is no comprehensive payments data currently available on how these devices may have affected cash use.)

3.4 Online commerce and digital economy

A development that has the potential to further reduce cash use is online commerce and the growth of the digital economy. For online purchases, the most common payment methods are credit cards and debit cards, and cash is typically

38 For the costs of debit cards and credit cards to merchants in Canada and Sweden, see Kosse et al. (2017) and Segendorff and Jansson (2012), respectively.

not accepted. In Canada, 69 percent of survey respondents in the 2017 MOP Survey made purchases online using a credit card or an online payment account (e.g., PayPal) in the month preceding the survey. And according to the Digital Economy Survey conducted by Statistics Canada, nearly 80 percent of Canadians aged 18 and above reported purchasing (or using free versions of) digital products such as music and video streaming services, e-books, online games, mobile applications and computer software between July 2017 and June 2018.[39]

In Sweden, according to the Riksbank's 2018 payment survey, 56 percent of respondents purchased goods or services online in the preceding month and 60 percent have used mainly a debit card or credit card for the online purchase. Online commerce is expected to continue growing, which is likely to further reduce cash use for transactions in both countries.

3.5 Summing up

The value of small-denomination bank notes in circulation has been declining consistently relative to GDP for many years in both Canada and Sweden. This decline corresponds with the finding that the use of cash for point-of-sale payments has been steadily decreasing in both countries, in absolute terms and as a share of payments, as Canadians and Swedes have increasingly relied on debit cards and credit cards. In Canada, the use of contactless payment cards has also grown quickly in the past few years and is likely to reduce cash use further, particularly for small-value point-of-sale transactions. In Sweden, contactless cards are still in the introductory stage, but they are likely to gain popularity rapidly, as has been the case in Canada. Other recent payment innovations are similar in the two countries, notably Interac e-Transfer in Canada (since 2001) and Swish in Sweden (since 2012), which have also contributed to reduced cash use in both countries, especially for P2P payments.

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39 For more, see Statistics Canada Digital Economy Survey

The use of cash versus other payment methods depends on both the consumer and merchant sides of the market. In practice, merchants tend to offer a range of payment choices that reflect their perceptions of consumer preferences, in order to maximize sales, conditioned by the costs of accepting different methods of payment. As a result, consumers drive the observed utilization of various payment methods over time, with merchant acceptance of different methods largely reactive in a competitive market. At the same time, as consumer preferences evolve (e.g., use less cash), merchants are more likely to move away from accepting cash, further discouraging consumers' use of cash. (For more on such interplay in the two-sided payment market, see Fung, Huynh and Kosse 2017, and Arvidsson, Hedman and Segendorf 2018.)

In sum, the long-term downward trend of small-denomination bank notes relative to GDP in Canada and in Sweden reflects declining transactional demand for cash in both countries, driven by the adoption of a range of similar retail payment innovations. And this trend is expected to continue. At the same time, merchant acceptance of cash has been (to this point) nearly universal in both Canada and Sweden. Since the end of the Second World War, transactional demand for cash in Sweden has declined more than that in Canada and is now at a very low level. However, our analysis suggests that payment innovations and their diffusion as well as merchant acceptance of cash have been similar in both countries. Accordingly, considerations related to such factors cannot explain the differences in aggregate cash-to-GDP trends in these two countries, particularly over the last decade or so. Next, we focus on non-transactional demand for cash to better understand this cross-country difference.

4. Larger-denomination notes and non-transactional demand for cash

The preceding section is concerned with the demand for cash used for purchases–that is, transactional cash demand. But bank notes can also provide a way to store value: cash is essentially free of credit risk, maintains its (nominal) value over time, can be exchanged at a later date for other assets, and used to purchase goods and services, without penalty. And large-denomination bank notes are a better (more efficient) store of value than small denominations. Indeed, holdings of large-denomination notes are usually considered to be motivated mainly by store-of-value considerations, rather than by payment needs, since the larger value of the notes makes them generally unsuitable for day-to-day transactions and comparatively more useful as a store of value. This perspective has probably become increasingly relevant over time as various technological payment innovations displace cash used for transactions.

This section argues that understanding the influences driving non-transactional–or store-of-value–cash demand is important for explaining the different experiences of Canada and Sweden when it comes to the evolution of aggregate cash-to-GDP over recent decades. These influences are discussed in the rest of this section.[40]

4.1 Store of value and a hedge against crisis

One aspect of holding larger notes as a store of value is related to increased demand during periods of political turmoil, recession or financial crisis, when such notes provide a safe store of "outside money"–in contrast to the "inside-money" balances held in the banking system.[41] For example, the financial crisis that began in 2008 appears to have had an incremental impact on the demand for cash in the most-affected countries; this is also evident in *Figure 3a*. More specifically, Bech et al. (2018, 77) show that the ratio of cash to GDP increased in advanced economies following the financial crisis, and they find a structural break in cash demand in 2007–08 for advanced economies (but not for emerging-market economies). They conclude that

40 The arguments in this section should be seen as suggestive and not conclusive. More definitive conclusions require more rigorous empirical examination, also drawing on other countries' comparative experiences, which is left for future research.

41 For a discussion of outside and inside money, and related motivations, see, e.g., Engert, Fung and Hendry (2018), especially Appendix 1 of that paper.

"the continuing demand for cash has been especially noticeable in advanced economies since the start of the great financial crisis, and is likely driven by store-of-value motives rather than payment needs."

Similarly, as discussed in Engert, Fung and Hendry (2018), the case of Iceland is especially striking and informative in this context. Between 2008 and 2010 Iceland experienced what could reasonably be considered a financial system collapse, when all of its major banks and savings banks failed (Kristinsson 2012). While significant government intervention aimed to mitigate the severe economic costs of the crisis, GDP nevertheless declined by over 11 percent in the two years after 2008 (Guðmundsson 2016). In that environment, the demand for bank notes–particularly large-denomination notes–briefly increased significantly, until government interventions stabilized the payment and banking system. And the ratio of cash to GDP in Iceland has remained elevated, as it has in almost all other countries affected by the 2008 financial crisis.

Similar influences on the demand for large-denomination bank notes in Sweden are apparent during the post-war period. For example, as shown in *Figure 5b*, demand for large-value notes relative to GDP increased with the erosion and collapse of the Swedish post-war economic policy framework in the 1970s. This culminated in economic crisis and repeated devaluations of the krona in the late 1970s and early 1980s, along with significant structural adjustments and political changes. Elevated holdings of large notes were generally sustained through the 1980s. There were also significant increases in total tax wedges in Sweden during the 1970s, which corresponded with significant income redistribution efforts (Du Reitz, Johansson and Stenkula 2015).[42] Higher taxation, in turn, could also have encour-

42 The marginal tax wedge on labour income includes marginal income taxes, marginal social security contributions and marginal payroll taxes. According to Du Reitz, Johansson and Stenkula (2015, 36), "tax wedges peaked around 1980 when the top marginal tax wedge and the marginal tax wedge for the high-income earner could reach 90 percent…The major tax reform in 1990–1991 decreased the marginal tax wedges to levels that prevailed before [the 1970s]."

aged activity in the underground economy and associated cash demand, which is discussed in Section 5 below.

As part of the associated policy adjustments following these events, financial liberalization in the 1980s led to a subsequent credit boom, especially in real estate–based lending. This, in turn, in the context of weak banking regulation and supervision, culminated in a severe financial crisis in the early 1990s.[43] (For more on these developments, see Carlgren 2015; Hogan 2010; Honkaphoja 2012; Schon 2008; and Wikfalk 1998).

In response to the banking crisis in the early 1990s, Swedish authorities initially responded in a piecemeal, ad hoc fashion. As the threat grew, however, policy-makers responded more aggressively to prevent a financial collapse. This ultimately included various supports for Swedish banks and the introduction in September 1992 of a blanket guarantee protecting depositors and other bank counterparties from loss. This was backed by open-ended funding for the Bank Support Authority created by the Swedish Parliament (Honkaphoja 2009; Jonung 2010). These formal banking system guarantees lasted until 1996. Sweden's response was ultimately widely regarded as a successful model of financial crisis management (see, e.g., Anderson 2009; Ergungor 2007; and Ingves and Lund 2008). Corresponding to these events, larger notes-to-GDP held as a store of value stabilized but continued at an elevated level through this period (*Figure 5b*).[44]

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43 Along with Sweden, two other Nordic countries, Finland and Norway, also experienced a systemic financial crisis in the early 1990s (Honkaphoja 2009, 2012). All four of the Nordic countries also provided public support to their banking systems in this environment. In Finland, Norway and Sweden, public support was significant, while in Denmark this support was small (Honkaphoja 2009).

44 The 500-krona note was introduced in 1985, and initially this note appears to have substituted for 1,000-krona notes as a store of value and the 100-krona notes for transactions. (Given persistent inflation in Sweden from the 1970s into the 1990s, the 500-krona note became more suitable for transactions during that period.)

During the 2008 global financial crisis, in contrast to the experiences of other countries, the demand for larger notes in Sweden increased only marginally and briefly. In fact, the value of 1,000-krona notes in circulation continued to decline throughout 2008 and 2009. Notably, following the lessons of the early-1990s banking crisis, Swedish authorities intervened promptly and aggressively to protect the financial system and inside-money balances. In October 2008, Swedish authorities introduced a comprehensive set of measures that provided state support to financial institutions and their creditors. These included liquidity assistance at short and longer maturities in SEK and in foreign currencies, guarantees of medium-term market debt issuances (which reached 10 percent of GDP), a bank-recapitalization scheme, increased deposit guarantee coverage, and a general stability fund to support other government interventions in the financial sector (Becker, Bryant and Henderson 2012; IMF 2011; and Jochen 2010). A central part of that program was legislation that gave the Swedish government unlimited fiscal powers to finance measures needed to ensure financial system stability, through guarantees, capital injections or other means. Distinguishing features of the Swedish crisis response were its promptness and thoroughness, as well as public transparency regarding both objectives and actions.

Senior Swedish officials have been clear that "a crucial lesson from the Nordic experience is the need for prominent state involvement in crisis resolution" (Ingves and Lund 2008, 21). Transparency is also seen as critical, including informing the public about official plans and actions. Finally, "there is also a role for a blanket guarantee to restore confidence and prevent bank runs and a potential financial meltdown" (Ingves and Lund 2008, 23).

It follows that Swedish authorities have demonstrated twice in the last 25 years comprehensive and transparent protection of the Swedish banking system and deposits under severe stress. And since the 2008 financial crisis, a new open-bank resolution framework has been established in Sweden for systemically important financial institutions (Riksgalden 2018b). Under this (bail-in) arrangement, Swedish authorities will take control of a systemically important institution that is deemed to be not viable. Furthermore, to avoid the broader adverse externalities from the closure of a systemically important bank, the institution will be kept open and functioning as usual so that depositors will have uninterrupted access to their accounts and other financial services.

These experiences and associated policy statements may have provided a disincentive for Swedes to hold cash as a store of value, and, in particular, larger bank notes (500-krona and 1,000-krona notes) as a hedge against crisis. In sum, there may be an expectation that, in periods of severe crisis, most deposits (inside money) will be secured by the actions of public authorities, thereby reducing the need for cash (outside money) as a hedge against crisis.[45]

Canada has had comparatively little experience with banking crises, although Canadian authorities deployed several measures supporting bank liquidity in response to the 2008 global financial crisis (Zorn, Wilkins and Engert 2009). As well, Canadian authorities have established a broad range of powers and policies to manage such events, also including an open-bank (bail-in) resolution framework for the major Canadian banks (Engert, Fung and Hendry 2018, Appendix 2). But there have not been repeated demonstrations of such intervention powers as in the Swedish experience.

4.2 Cashless bank branches

As noted above, larger bank notes in both Canada and Sweden are handled mainly in bank branches. Therefore, the ease of accessing cash services from branches influences the holding of larger notes as a store of value. As shown in *Figure 4b*, there are significantly more bank branches per capita in Canada compared with

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45 A similar proposition arguably might apply for some other advanced economies, but perhaps has been less clearly demonstrated in practice than has been the case in Sweden.

Sweden (roughly 50 percent more).[46] The number of branches in Sweden began to decline following the 2008 financial crisis, as branch network rationalization has been part of broader cost-reduction efforts by Swedish banks. Further, many bank branches in Sweden have become cashless in recent years. That is, no cash services on demand are available at such branches, and at the minority where cash services are available, advance notice is required. Moreover, Bankomat has been installing ATMs in cash centres that are located in shopping malls instead of at bank branches to facilitate cash withdrawals for shopping. As a result, bank branches in Sweden are increasingly without any cash access at all, including without on-site ATMs.

Cashless bank branches in Sweden started in 2010 as a cost-reduction measure of the banks and have spread rapidly. In 2010, about 10 percent of Swedish branches became cashless, around 40 percent were cashless in 2012, and by 2016, 60 percent of Swedish bank branches were cashless.[47] And it is likely that this proportion has increased further since then. For instance, the exchange at bank branches of new Swedish banknotes for older, invalid series starting in 2015 was finished in 2017 (see below), which reduced ongoing demand for cash services and the banks' incentives to supply them after that point. The increasing share of cashless bank branches is also reflected in Swedish banks' cash holdings, which declined from SEK 9 billion at the end of 2010 to less than SEK 2 billion at the end of 2018. This trend to cashless branches probably has inhibited access to the largest bank notes in particular–that is, 1,000-krona notes.[48] In this regard, the value of 1,000-krona notes in circulation dropped from over SEK 21 billion in 2012 to SEK 10 billion in

46 And there is some evidence that bank branches in Canada are becoming (even) more central to major Canadian banks' retail business strategies. See, e.g., T. Kiladze, "TD Bank's Radical New Strategy," The Globe and Mail, December 2, 2018.
47 See Swedish Bankers Association Bank and Finance Statistics and Statens Offentliga Utredningar (2018).
48 According to Bankomat, note denominations up to 500 krona are usually available in Swedish ATMs, subject to withdrawal limits set by each bank.

2013, and to just over SEK 3 billion in 2018. Further, this friction has been exacerbated by increasingly stringent anti-money laundering (AML) provisions.

As noted, the Swedish Bankomat ATM network (discussed above) provides for access to most smaller-denomination notes, so cashless branches are not a significant constraint on access to transactions cash. Instead, they appear to generate a friction inhibiting access to large-denomination, store-of-value notes in Sweden, particularly since 2010. In addition, as noted above, ATMs in Sweden are mainly for cash withdrawals, and only specific deposit machines accept cash deposits. Thus, together with the increasing number of cashless branches, it has becoming increasingly difficult to deposit cash, which could discourage the acceptance of cash in general.

Cashless branches could also inhibit merchants' willingness to accept cash at point-of-sale, given the increased cost to merchants of cash management arising from the proliferation of cashless branches. (This might especially affect small and medium-sized merchants.) For example, merchants that accept cash need to keep a sufficient amount of small denominations (e.g., 20-krona and 50-krona notes) on hand for change. Since Swedish ATMs do not dispense such small denominations, merchants must find a branch that provides cash services or they risk not having sufficient change. And to deposit cash received during the day, in the absence of a suitable bank branch that accepts cash or has a drop-off box, merchants increasingly depend on the services of cash-in-transit companies to deliver deposits and to obtain change–which increases merchants' cost of accepting cash. Indeed, Swedish authorities have identified the limited access to deposit services as a problem for businesses (Statens offentliga utredningar 2018).

As noted above, there are significantly more bank branches per capita in Canada than in Sweden, and almost all Canadian bank branches provide cash services on demand. In the last few years, some of the major Canadian banks have introduced branches that focus exclusively on the provision of financial advice and sales to consumers. This includes providing mortgages and other lending, investment and wealth management, as well as business services for small and medium-sized firms. These "financial-advice centres" do not provide any cash services over the counter (teller) but could provide access to cash through on-site ATMs. To date, such bank branches without over-the-counter cash services are relatively unusual in Canada, but they could be under consideration more generally by the major banks.

For example, it appears that 18 percent of the branches of one of the major Canadian banks are now cashless or tellerless (i.e., no cash services are provided at the counter), based on information collected online. ATMs are present at these branches and can dispense a range of bank notes, including \$100 notes, and accept deposits including stacked cash and cheques. As well, daily ATM withdrawal limits can be increased when needed, including to satisfy individual customer requests arranged on the spot with branch staff or in advance via telephone banking. More generally, ATMs in Canada increasingly provide consumers with a range of choice about the denomination of notes dispensed in ATMs, up to and including \$50 notes. Some banks are also considering stocking their ATMs with \$100 notes. As a result, in contrast to the Swedish case, there do not seem to have been meaningful frictions inhibiting access to large-denomination notes in Canada due to cashless bank branches. However, some variant of cashless branches could proliferate in Canada in the future.

The evolution of cashless bank branches seems to reflect interactions characteristic of a two-sided market, similar to that discussed above concerning payment methods. More specifically, customer preferences regarding access to cash (e.g., over-the-counter versus ATMs, choice over denominations, etc.) are the fundamental drivers in a competitive banking market, with banks responding strategically to these evolving customer preferences. At the same time, banks' decisions about access to cash, which are also influenced by cost considerations, can consolidate or reinforce the underlying trends in access to cash driven by customer preferences.

(If, however, the banking market is not competitive or banks collude in this respect, then consumer preferences would be less dominant.)

4.3 Legal tender provisions

In Sweden, when a new series of bank notes is issued, the old series becomes invalid and loses its legal tender status after a certain terminal date. Loss of legal tender status appears to be a relatively frequent event in Sweden, occurring a few times since 1987 (*Table 1*). For example, many older series of bank notes, including most denominations of notes that were issued between 1890 and 1962, became invalid after December 31, 1987. Moreover, legal tender status of almost all note series that were issued between 1963 and 2000 became invalid either on December 31, 1998, or on December 31, 2005. Prior to 2015, the terminal date for old notes tended to vary over time and was usually several years after the issuance of a new series. However, when the latest series of bank notes were issued in 2015 and 2016, old series of bank notes became invalid in less than one year. For example, new 1,000-krona notes were issued on October 1, 2015 and all of the old 1,000-krona notes (first introduced in 2006) became invalid after June 30, 2016. Since the new notes differ from the old notes, both in design and size, the short exchange period was intended to help reduce costs to banks and the public that could arise from having different sets of notes in circulation.

To redeem old bank notes *before* they become invalid, note holders must exchange them at a bank branch offering cash services, which, as noted above, are becomingly increasingly difficult to find. In practice, to facilitate the introduction of new notes, banks in some cases continued to accept invalid notes for a period after the official terminal date (consistent with an understanding between the Riksbank and the banks).[49]

49 The 20-, 50- and 1,000-krona notes became invalid after June 30, 2016 but were accepted for exchange by banks for two additional months. Similarly, 100- and 500-krona notes became invalid after June 30, 2017 but were accepted for exchange by banks for an additional year.

To redeem old bank notes after the exchange period, note holders must mail their notes to the Riksbank to obtain a corresponding deposit into their bank accounts. There is a fee of SEK 100 for each such exchange transaction, and applicants must provide certain attestations to the Riksbank. That is, note holders must explain how they acquired the notes, and why the notes were not used for transactions nor exchanged while they were legal tender.[50] The Riksbank may also ask for additional documentation when considering the application, particularly the amount. This process applies to all holders of Swedish bank notes, including foreign note holders.[51] As a result, in addition to generating cost and inconvenience for note holders, these exchange provisions undermine the maintenance of privacy of cash holdings–a particular (and legitimate) motivation for holding bank notes as a store of value. Further, these frictions appear to have been growing more severe over time in Sweden. For example, as noted above, generally shorter (and variable) exchange periods have applied over time to more recent new note issuances.

In sum, the frequency with which bank notes have been deemed invalid in Sweden over the last 20 years and the burdensome exchange provisions in some cases, especially coupled with the decreasing availability of cash services at bank branches, have probably undermined the demand for cash, particularly larger notes, as a store of value. A notable example is the decline in 1,000-krona notes in circulation over the last two decades. After peaking in December 2001 at SEK 48.4 billion, the value of 1,000-krona notes declined gradually to SEK 21.4 billion in December 2012. Beginning in 2013, this decline accelerated, and the outstanding value de-

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50 Additional information and requirements concerning redemption of invalid notes are available at the Sveriges Riksbank website ("Redeeming invalid banknotes"). These requirements reflect the increasingly stringent AML /CTF regulations in Sweden (e.g., people who deposit more than SEK 10,000 are required to account for the sources of the cash).

51 From 2015 to 2018, the Riksbank received 220,662 note-exchange applications, worth over SEK 1 billion. The number of such applications has been increasing recently. In 2017, there were 63,723 such applications, and in 2018 there were 67,411. (These applications can also cover very old bank notes, e.g., notes issued in the early 1900s that were declared invalid in the 1980s.)

creased to SEK 9.7 billion by December 2013. Subsequently, this decline levelled off (see Box 1 for a detailed discussion of the experience regarding legal tender provisions affecting the 1,000-krona note).

In contrast to these Swedish legal tender frictions, all bank notes issued by the Bank of Canada remain legal tender. Recently, legislation has been passed to allow the Bank of Canada to change the legal tender status of a denomination of a series of bank notes. The current plan is to remove the legal tender status of certain denominations of notes that have long been discontinued and are no longer issued: \$1, \$2, \$25, \$500 and \$1,000 notes.[52] There are no plans to remove the legal tender status of any other bank notes. Therefore, there are no legal tender frictions suppressing demand for larger bank notes in Canada.

Box 1: Additional information on legal tender provisions affecting the 1,000-krona note

The legal tender frictions associated with the issuance of new 1,000-krona notes in 2006 and again in 2015 appear to have contributed to the rapid decline of 1,000-krona notes, particularly in 2013 (*Figure 1-A*). With the introduction of the new 1,000-krona notes in 2006 (an improved note with a security foil strip), the 1,000-krona notes issued from 1989 to 1991 (without a foil strip) were scheduled to become invalid on December 31, 2013. (Similarly, the 50-krona note without foil strip was also deemed invalid after December 2013 and replaced.) Thus, holders of the old 1,000-krona notes had to exchange them for new notes at a bank branch before the end of 2013. In 2012, however, the Riksbank announced its intention to issue another new series of bank notes in 2015 and 2016, including another new 1,000-krona note, which would make all pre-existing series of bank notes invalid sometime after

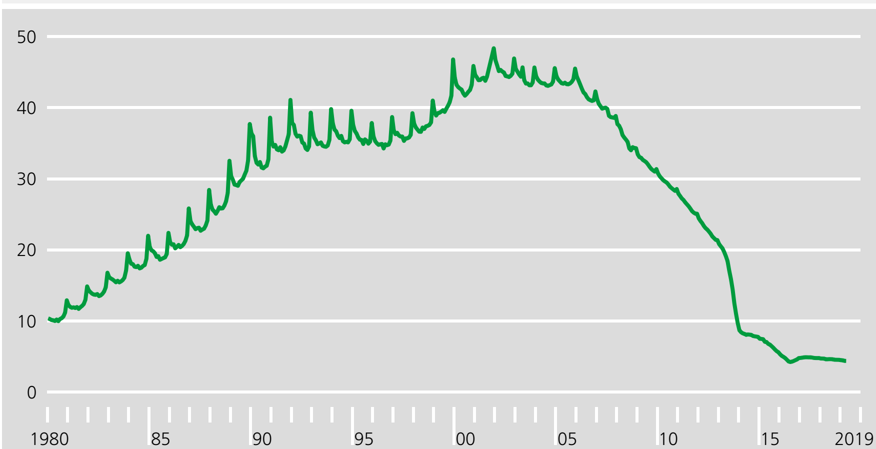
52 See upcoming changes to legal tender status for older bank notes at the Bank of Canada.

2016. This could have had an impact on note holders' decisions to exchange their old 1,000-krona notes (no foil strip) for those issued after 2006 (with foil strip) before the end of 2013, which would become invalid sometime after 2016—or to simply exchange their old 1,000-krona notes (no foil strip) for bank deposits before the end of 2013.

Further, as discussed above, cashless bank branches started emerging in Sweden in 2010, and many bank branches (more than 40 percent of them) were cashless by 2012. The number of cashless branches has continued to grow, making it increasingly difficult to exchange old bank notes for new notes. As a result, the frequent replacement of 1,000-krona notes, combined with an increasing number of cashless branches, exacerbated the inconvenience and cost of exchanging outstanding 1,000-krona notes, likely contributing to the sharp decline in the circulation of these notes in 2013.

Value of 1000-krona notes in circulation Figure 1A

SEK billion



Source: Riksbank.

4.4 Other considerations

(i) Domestic demand for large-value foreign notes

Canada and Sweden both have strong ties with much larger, influential neighbours: i.e., the United States and euro area economies, respectively. Have residents of the former increased their holdings of large-value foreign notes as a store of value? If so, this could reduce demand for larger domestic notes in favour of foreign notes. There appears to be little evidence that Canadians have been swapping large-value Canadian notes for US notes as a store of value.

Have Swedes dropped larger-value SEK notes in favour of euro note holdings as a store of value? If interpersonal trust or trust in Swedish institutions was very low in Sweden compared with major countries of the euro area, for example, Swedes might switch their holdings from large-denomination SEK notes to large euro notes or to deposits of major non-Swedish banks. The evidence, however, indicates that interpersonal and institutional trust in Sweden is consistently (and substantially) among the highest in Europe (Ortiz-Ospina and Roser 2018). And, as discussed above, Swedish authorities have gone to considerable lengths to provide for the robustness of their banking system under stress. More generally, there seems to be little evidence that Swedes have been swapping their large-value SEK notes for large euro notes as a store of value.

(ii) Foreign demand for large-value domestic notes

Some anecdotal evidence suggests an increase in foreign demand for large-denomination Canadian bank notes in recent years, but this is not well understood (Flannigan and Parsons 2018). The strong increase in demand for Canadian notes after the 2008 global financial crisis, especially for larger denominations, could reflect diversification of foreign demand toward a relatively stable financial system. As the global financial system continues to stabilize over time, this demand might dissipate.

In addition, the steady growth of immigrants, international students and tourists coming to Canada might have also contributed to increased foreign demand for

Canadian bank notes. For example, the number of immigrants to Canada increased from 248,748 in 2011 to 286,479 in 2017.[53] The top three source countries for immigrants were India, the Philippines and China, accounting for 43 percent of all immigration in 2017, for example. Also, the number of international students studying in Canada has been increasing at a steady rate over the last two decades, and the increase has accelerated since 2008–09.[54] In 2016–17, international students totalled 245,895, accounting for 12 percent of total enrolments in Canadian post-secondary institutions. Over 50 percent of the international students in Canada are from Asia, with China and India the most important source countries. Finally, the number of international tourists visiting Canada has been increasing steadily since 2009, with over 6.5 million tourists from countries other than the United States in 2017. Historically, these travellers have come predominantly from Europe. However, Europe's share of overseas travellers has declined while the number of Asian tourists has doubled (2.3 million in 2017) since 2009.[55]

Notably, China and India, two of the main source countries for immigrants, international students and tourists coming to Canada, have imposed capital controls, including restrictions on the purchase of foreign currencies by their nationals. For example, Chinese citizens are allowed to purchase foreign currencies in amounts equivalent to up to US$50,000 per person, per year. (While this annual allowance would seem adequate for most peoples' overseas travel needs, it might not be sufficient for major investments overseas, such as purchasing a property.) Also, Chinese visitors to Canada are likely to hold some Canadian bank notes when entering Canada for convenience and wide acceptance, particularly since Chinese citizens have had limited access to major global card companies' products. (However,

53 See Annual Report to Parliament on Immigration by Immigration, Refugees, and Citizenship Canada, various years.
54 For details, see Statistics Canada, "International Students in Canadian Universities" and "Canadian Postsecondary Enrolments and Graduates, 2016/2017."
55 See Statistics Canada, "The Evolution of Canadian Tourism, 1946 to 2015" and "Travel Between Canada and Other Countries, December 2017."

"China UnionPay" cards, the main debit and credit cards accessible by Chinese nationals, are increasingly accepted in Canada.) Also, international students and immigrants from China might acquire Canadian bank notes before arriving in Canada so that they can make purchases until they have set up a domestic bank account.

Sweden also has experienced substantial immigration in recent decades, as indicated by the 2.4 million residence permits granted between 1980 and 2018, of which nearly half were granted after 2008.[56] Roughly one-quarter of the latter were granted for asylum reasons, one-quarter for labour market reasons (i.e., pursuing work opportunities) and one-third were family unifications.[57] Ten percent of the residence permits were issued to students, foremost from China and India. (European Union citizens moving to Sweden are not included in these data.) As well, there has been labour immigration from some Eastern European countries following their accession to the European Union in 2004.[58] In sum, most immigration to Sweden in recent decades has been from cash-intensive countries, and this might have increased the demand for cash, at least for a period before the immigrants adapt to local Swedish practices. There is, however, no concrete evidence supporting this perspective. Indeed, the rapid decline of cash demand in Sweden in recent years seems to suggest that this influence has been negligible.

Likewise, there are no data on the holdings of Swedish bank notes abroad, for example, in immigrant countries of origin. Some insight might be gained from the invalid bank note exchange applications sent to the Riksbank in 2015 and subsequent years: Around 15 percent of all such applications are made by foreign citizens, often from Eastern Europe. If these numbers are representative of the

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56 Statistics on granted permits can be found at Swedish Migration Agency. (More detailed statistics are available in Swedish.)

57 The most common countries of origin for refugees were Syria, Afghanistan, Eritrea, Somalia and Iran. For family unification, main source countries were Syria, Iraq, Afghanistan, Eritrea and Somalia. And major source countries for labour market reasons were India, Thailand, China, Albania and Turkey.

58 Most of this labour came from the Baltic states and Poland.

distribution of SEK notes generally, then there could be almost SEK 1 billion held abroad.[59] Even if foreign SEK holdings were somewhat higher than this estimate, they would still be a relatively low amount compared with the total demand for cash and would not likely have had a significant effect on the demand for high- or low-denomination notes.

In sum, an increase in foreign demand for Canadian bank notes might have contributed to the strong demand for large-denomination notes in recent years. While there are some possible explanations for this increase in foreign demand, as noted above, this is not well understood. A better understanding of the foreign demand for cash requires better data (including, e.g., data on the shipment of Canadian bank notes overseas), along with more rigorous analysis of foreign sources of demand.[60]

4.5 Summing up

The divergent trends of cash demand in Canada and Sweden since 2000 have been driven largely by developments affecting larger notes–that is, $50 and $100 notes in Canada, and 500-krona and 1,000-krona notes in Sweden. Several influences together appear to have led to reduced demand for larger, non-transactional notes in Sweden.

Sweden's crisis-management experience may have created incentives that discourage reliance on large notes as a hedge against uncertainty. In addition, the proliferation of cashless bank branches and the operation of Swedish legal tender rules appear to have created frictions that inhibit holdings, especially of larger Swedish

59 At the end of 2018, SEK 5.5 billion in invalid notes were in circulation. Fifteen percent of this is close to one billion.
60 For example, it would be useful to understand whether people from a cash-oriented country are more likely to accumulate and carry foreign bank notes when travelling overseas or when immigrating to another country. Kosse and Jansen (2013) find that first-generation migrants from a number of countries that can be seen as cash-oriented are more likely to use cash in the Netherlands.

notes. At the same time, foreign sources could have generated increased demand for large-denomination Canadian bank notes in recent years (which could diminish over time). Taken together, these various influences and frictions help to explain relatively low demand for store-of-value cash in Sweden compared with Canada. (Recently, there has been a modest uptick in holdings of 500-krona notes; see Box 2 for more on this.) More definitive conclusions require further empirical examination, drawing also on other countries' experiences, which is left for future research.

Box 2:

Since late 2017, there has been an increase in the (absolute) value of bank notes in circulation in Sweden, driven by an increase in 500-krona notes (see *Figure 2-A* below). (This has had little discernable impact on the value of 500-krona notes relative to GDP.) The reasons for this modest reversal are not entirely clear, but it likely reflects a buildup of cash buffers of households. One possible reason for this is a recent Swedish government initiative to increase reliance on cash as a hedge against crisis. To this end, an agency of the Swedish government (the Swedish Civil Contingencies Agency) provided every Swedish household a booklet entitled If War of Crisis Comes to help Swedish citizens be better prepared for a range of calamities, including serious accidents, extreme weather, information technology dysfunction and military conflict. The booklet also points specifically to disruptions in payment card and ATM networks. (See the Swedish Civil Contingencies Agency website for more information.) Accordingly, the agency recommends, among other things, that citizens hold a buffer of cash in small denominations at home, and it appears that Swedes have decided that 500-krona notes (which are available from ATMs) can address this need.

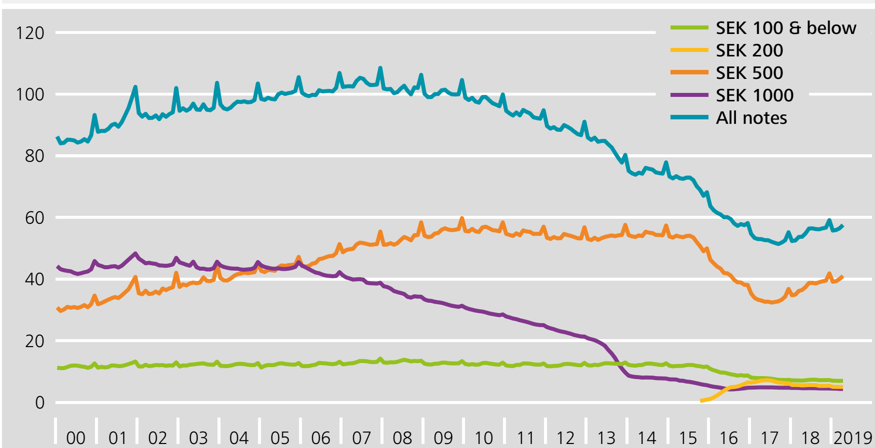
The crisis preparedness booklet was sent to households in May 2018, but news about its circulation and its key recommendation were publicly available since at least January 2018. (See, for example, "What If War Comes," in The Irish Times, January 18, 2018.) The authorities also previously posted the key recommendation on its webpage. A version of this booklet was issued regularly in Sweden during the Cold War, from 1943 to 1991. And Swedish authorities have been gradually increasing their focus on security policy over the last 10 years or so.

The recent buildup of this cash buffer could also reflect an element of involuntary cash hoarding by households and businesses, given the difficulty of depositing bank notes in Sweden (as discussed in the text). It is also possible that households did not fully restore their cash buffers to their desired level during the last bank-note exchange and have been gradually doing so recently in 500-krona notes.

Value of Swedish bank notes in circulation

Figure 2A

SEK billion



Source: Riksbank.

5. Demand for cash and the underground economy

A connection is often made between the underground (or shadow) economy and cash. This section considers that connection and whether it plays a significant role in explaining the differences in the evolution of cash-to-GDP in Canada and Sweden.

5.1 Background

The focus here is the underground economy, in which the underlying activities and transactions are legal but are concealed from public authorities for a variety of reasons. Following Schneider (2016), we consider the underground economy as including market-based, legal production of goods and services that are concealed from public authorities largely to avoid one or more of the following:

- payment of taxes, such as income taxes or value-added taxes
- payment of social security contributions
- compliance with administrative procedures, such as completing statistical questionnaires
- certain labour market standards, such as minimum wage or safety requirements

Given the intent to conceal the benefits of the underlying activity, it seems reasonable to conjecture that cash, which provides for anonymity, is a preferred means of payment in the underground economy. As a result, one could expect that changes in the size of the underground economy might help explain cash demand over time.

While the preceding provides a straightforward conceptual definition, reliably measuring the size of the underground economy is, of course, challenging. Further, there are typically large discrepancies in estimates depending on the empirical methodology used, and there does not appear to be a preferred or dominant approach to measuring the underground economy (Dunbar and Fu 2015; Medina and Schneider 2018).

In Canada, for example, Dunbar and Fu (2015) note that studies using discrepancies in national accounts to measure the amount of unreported income estimate the underground economy at about 3 percent of GDP, while studies using microeconomic consumption data result in estimates of around 5 percent. And studies based on macroeconomic data find that the size of the underground economy in Canada could be as much as 15 percent of GDP. Similarly, Dunbar and Fu (2015) use household-level income data and consumption data to estimate under-reported income, and they conclude that an upper bound of 14 to 19 percent of GDP is unreported in Canada.

With respect to Sweden, Guiborg and Segendorf (2007), using an unexplained-demand-for-cash approach, measure the size of the underground economy in Sweden to be 6.5 percent of GDP in 2006. In comparison, Medina and Schneider (2018), using macroeconomic and other data, estimate it at 11.1 percent in 2006.

Similarly large discrepancies across quantitative methods are evident for many other countries (e.g., Medina and Schneider 2018; Seitz, Reimers and Schneider 2018). In their review, Medina and Schneider (2018, 28) conclude, "There is no superior method [to measure the underground economy]. All methodologies, without exception, have their own advantages as well as weaknesses. If possible, one should use multiple methods [to draw conclusions] … Much more research is needed with respect to the estimation methodology and the results for different countries and periods."[61]

These authors also observe, however, that one stable conclusion from the evidence is that the size of the underground economy (relative to GDP) appears to have been generally declining across a wide range of economies (advanced and emerging) from 1991 to 2015 (interrupted only in 2008, likely due to the global economic crisis).[62] *Table 2* illustrates this aspect for Canada and Sweden.

Further, while it is reasonable to expect that the underground economy is relevant for explaining cash demand, in practice it is difficult to establish a meaningful em-

61 See also Schneider and Buehne (2017) for a related discussion.
62 This conclusion is based on a "Multiple Indicators Multiple Causes" (MIMIC) method to measure the underground economy. In MIMIC approaches, the shadow economy is formalized as the outcome of a multitude of measurable causes such as tax rates, the degree of regulation and the level of unemployment (Seitz, Reimers and Schneider 2018; Medina and Schneider 2018).

pirical relationship between cash and measures of the underground economy. This appears to be the case across a number of countries and a variety of studies (Seitz, Reimers and Schneider 2018).[63]

5.2 Swedish policy measures to reduce the size of the underground economy

Given concerns in Sweden about undeclared work and revenues, the Swedish Tax Agency has established several measures to reduce tax evasion in sectors with high cash turnover. A focus has been domestic services, such as home repairs, cleaning and home maintenance, where it is believed that such work traditionally has been undeclared to a significant extent (Swedish Tax Agency 2012). Accordingly, to reduce the prominence of the underground economy in Sweden and bring activity into the taxable, formal economy, tax deductions for 50 percent of the labour cost of certain domestic work were introduced in 2007 (for household services, so-called "RUT" provisions) and in 2008 (for home renovations, the "ROT" provisions). These measures provide tax incentives to pay for such services in the declared, formal economy, and therefore to discourage transactions in the underground economy.

These measures appear to have been effective in bringing some activity into the formal economy and reducing tax evasion (Swedish Tax Agency 2012). For example, surveys have indicated that, between 2006 and 2012, the proportion of citizens who know people who have evaded tax or participated in the underground economy during the preceding 12 months decreased significantly. More specifically, the proportion of respondents who know people who evaded tax decreased from 22 to 13 percent, and the proportion of respondents who know people working in the underground economy decreased from 38 to 22 percent. Swedish authorities consider these changes likely to be the result of the tax deductions de-

63 This is perhaps not surprising given the characteristics of cash (in particular, anonymity) and the nature of the underground economy (which is intended to be obscure).

scribed above for house repair and maintenance and for domestic work (Swedish Tax Agency 2012, 16)

The commercial sector has also been a focus for Swedish authorities, where there have been concerns about the manipulation of cash registers and associated under-reporting of revenues, particularly in businesses with high cash turnover (Eurofound 2013). Accordingly, starting in January 2010, businesses in Sweden selling goods and services for cash payments must use a certified cash register that includes a control unit ("black box"), which records transactions made by the cash register. Only the Swedish Tax Agency can access the sales and payment records in the black box.[64] Analyses by the Agency (2013) indicate that this measure also appears to have reduced the extent of commercial tax evasion in Sweden.

5.3 Summing up

Given the outcomes reported by the Swedish Tax Agency (noted above), it follows that there would have been corresponding decreases in the size of the underground economy (other things equal) and cash demand in Sweden. Such outcomes would have contributed to the overall decline of Swedish cash-to-GDP during the last decade (discussed in earlier sections). On the other hand, given the considerable uncertainty in the measurement of the underground economy and its (empirical) relationship to cash demand, it is difficult to draw (strong) conclusions about the significance of these tax-policy measures in reducing cash demand in Sweden.

Moreover, as noted, numerous countries in the last 10 to 20 years have experienced a general trend of declining underground economies, including Canada. If this is correct, other (perhaps common) underlying factors might also be relevant. From this perspective, it seems unlikely that a declining underground economy in

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64 Businesses bear the costs of installing and maintaining these monitored cash registers, and non-compliance is subject to fines levied by the Swedish Tax Authority.

Sweden driven by tax changes explains the different experiences of cash-to-GDP in Canada and in Sweden.

6. Conclusions

Cash use for payments has been decreasing in many countries, including Canada and Sweden. However, notes in circulation relative to GDP in most countries, including Canada, have been stable for decades and even rising in recent years. In contrast, overall cash-to-GDP in Sweden has been falling steadily. To understand these outcomes, we focus separately on transaction (small-denomination) bank notes and store-of-value (large-denomination) bank notes.

Both Canada and Sweden have seen a long-term downward trend in small-denomination bank notes relative to GDP, reflecting declining transactional demand for cash in both countries. These outcomes have been driven by the adoption of a range of similar retail payment innovations. At the same time, merchant acceptance of cash has been (to this point) nearly universal in both Canada and Sweden. Therefore, neither payment innovations and their diffusion nor differences in merchant acceptance of cash are adequate to explain why aggregate cash demand has been declining rapidly in Sweden but not in Canada.

Instead, divergent trends in the demand for larger bank notes, typically used more as a store of value, seem to be the key to understanding the different overall cash-to-GDP trends in Canada and Sweden. More specifically, Sweden's crisis-management experience may have created incentives that discourage reliance on large notes as a hedge against uncertainty. In addition, the recent proliferation of cashless bank branches and the operation of Swedish legal tender rules appear to have created frictions that inhibit holdings of larger Swedish notes. These three influences work in the same direction to reduce demand for larger bank notes, and to some extent have probably reinforced each other to generate larger cumulative effects on cash demand over time. In Canada, some evidence suggests that foreign sources could have generated increased demand for large-denomination Canadian bank notes in recent years (which could diminish over time).

The analysis in this paper points to three broad lessons:

- (i) Policy interventions and bank resolution frameworks (e.g., bail-in) that credibly protect depositors ("inside money") in financial crises reduce incentives to hold larger bank notes as a hedge against crises. Such interventions very likely are unavoidable in extreme (tail-event) financial crises and indeed are justifiable, particularly if the resolution framework is well-structured ex ante (as are some bail-in regimes). These considerations also suggest a reduced need for a central bank digital currency as a safe store of value in crises (as discussed in Engert, Fung and Hendry 2018).
- (ii) Cashless bank branches create a friction inhibiting access to cash, depending on the ability of ATM networks to satisfy consumer demand for bank notes across a range of denominations and to provide adequate cash-deposit services, particularly for merchants. Given the need for merchants to manage relatively large volumes (and values) of bank notes, cashless bank branches can create disincentives for merchants to accept cash at the point of sale, which would inhibit the use of, and demand for, bank notes.
- (iii) Legal tender rules, where old bank note series are declared invalid, create frictions that inhibit the demand for cash. The impact of such measures is stronger the more frequently these declarations occur and the more burdensome and variable the provisions are governing the exchange of old (invalid) notes for new notes. In that case, legal tender frictions can be expected to reduce the demand for bank notes, particularly as a store of value.

Finally, more work is required to better understand the demand for larger Canadian bank notes, including the role of foreign demand, which is left for future research.

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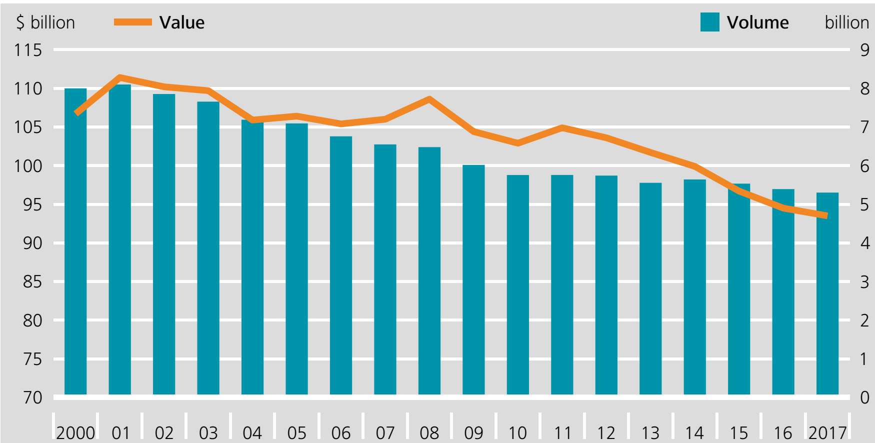
Number and value of cash transactions in Canada

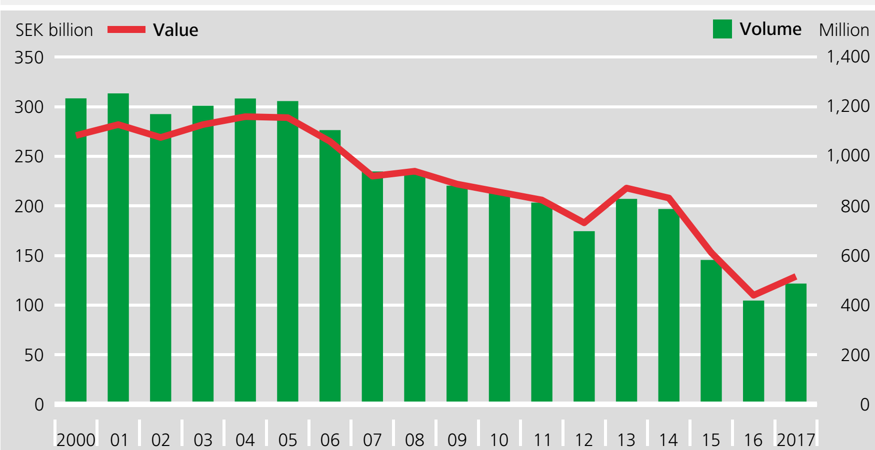
Figure 1a



Sources: TSI International and authors' calculations.

Number and value of cash transactions in Sweden

Figure 1b

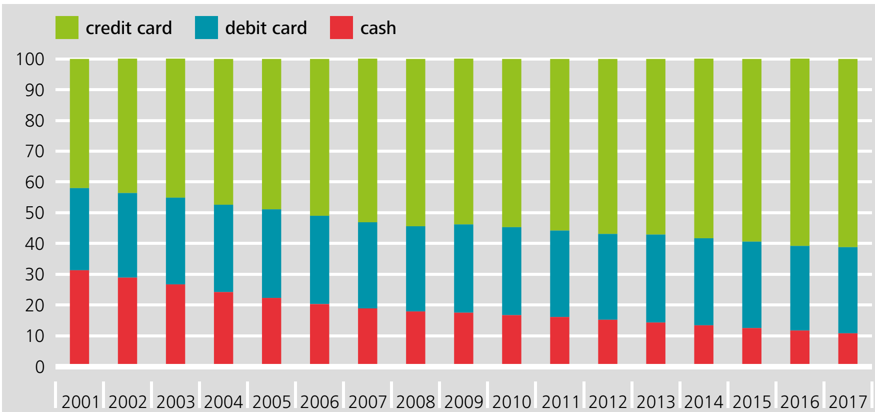


Sources: Bank for International Settlements and authors' calculations.

Value share of cash, debit card and credit card payments in Canada

Figure 2a

%

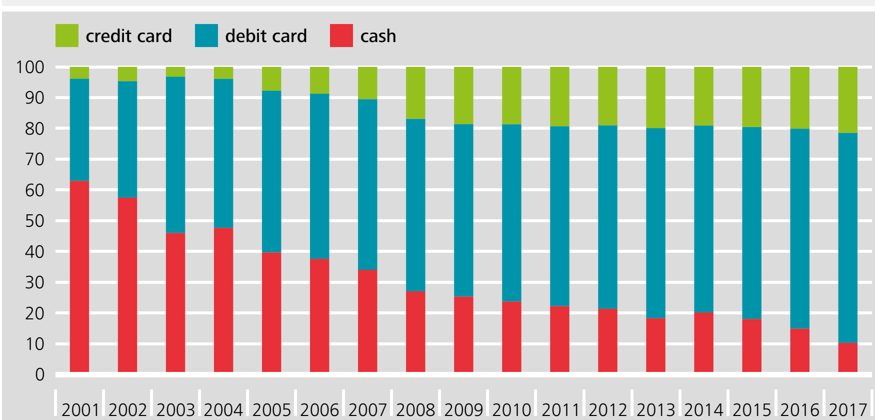


Sources: TSI International and authors' calculations.

Value share of cash, debit card and credit card payments in Sweden

Figure 2b

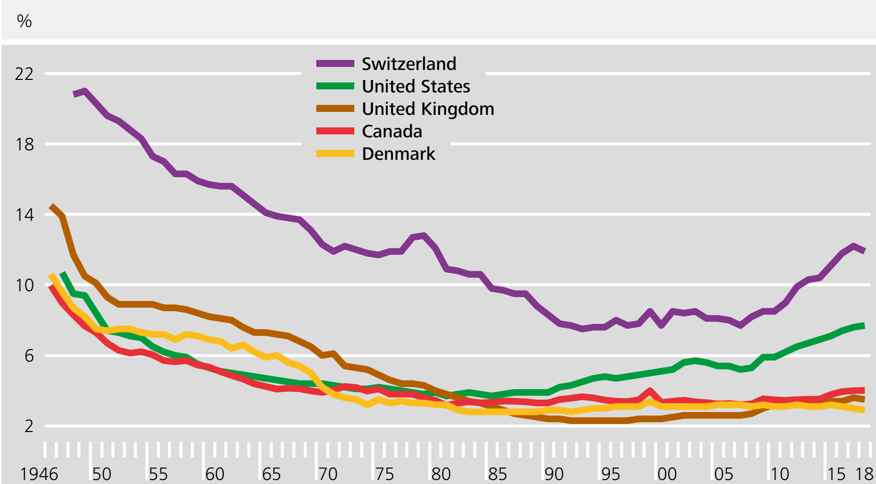
%



Sources: Bank of International Settlements and authors' calculations.

Bank notes as a ratio of nominal GDP for selected countries

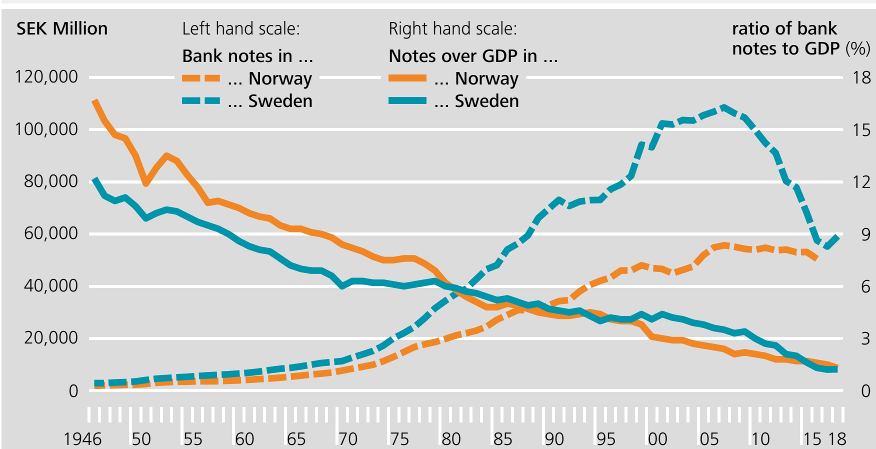
Figure 3a



Sources: Bank notes data from central banks and GDP data from national account statistics in respective countries.

Bank notes as a ratio of nominal GDP in Norway and Sweden

Figure 3b

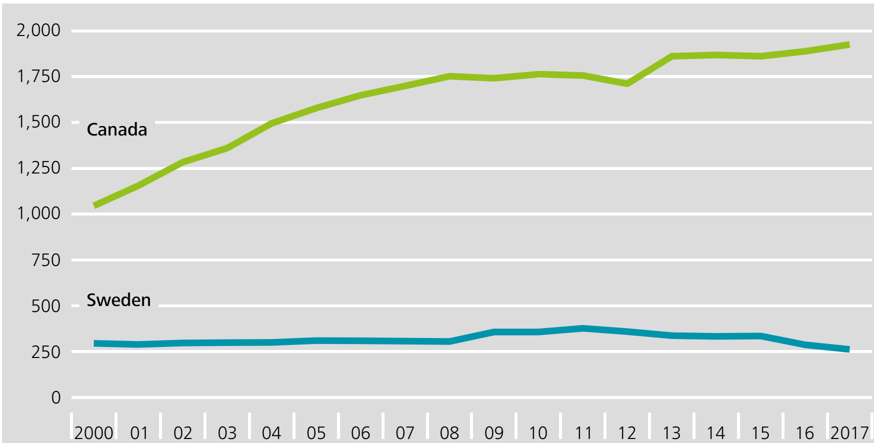


Sources: Sveriges Riksbank and Norges Bank.

Number of ATMs in Sweden and Canada

Figure 4a

per million of inhabitants

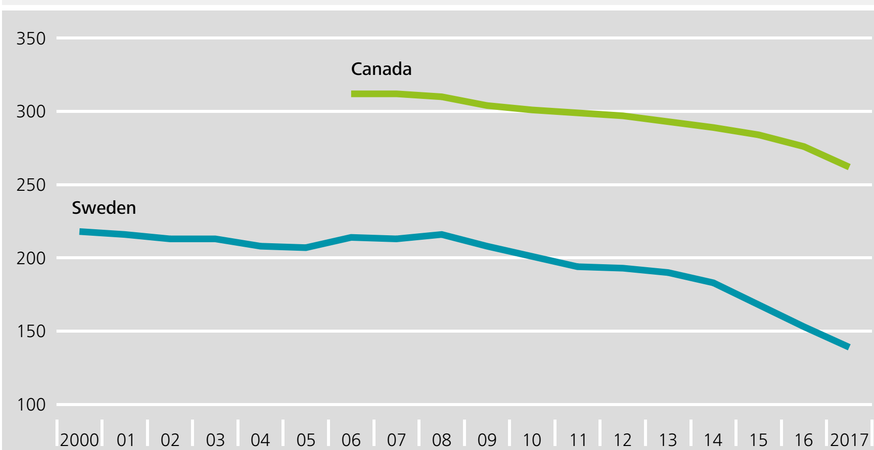


Sources: Bank of International Settlements and authors' calculations.

Number of bank branches in Sweden and Canada

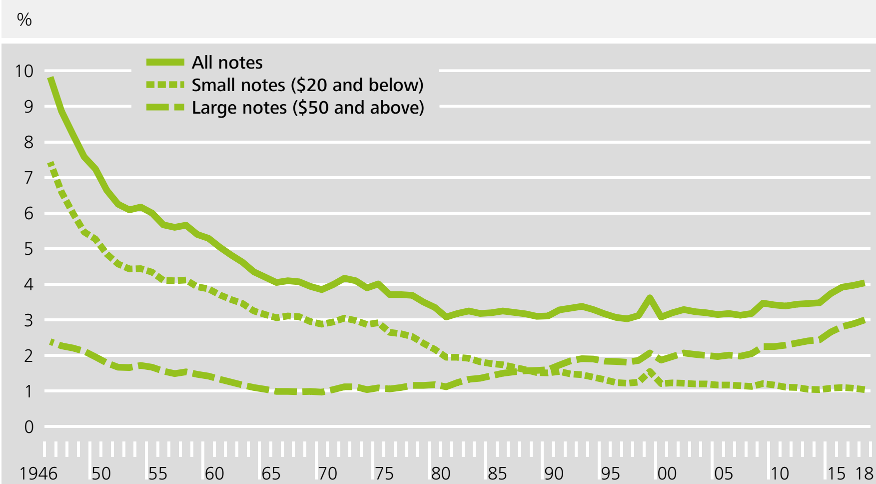
Figure 4b

per million of inhabitants



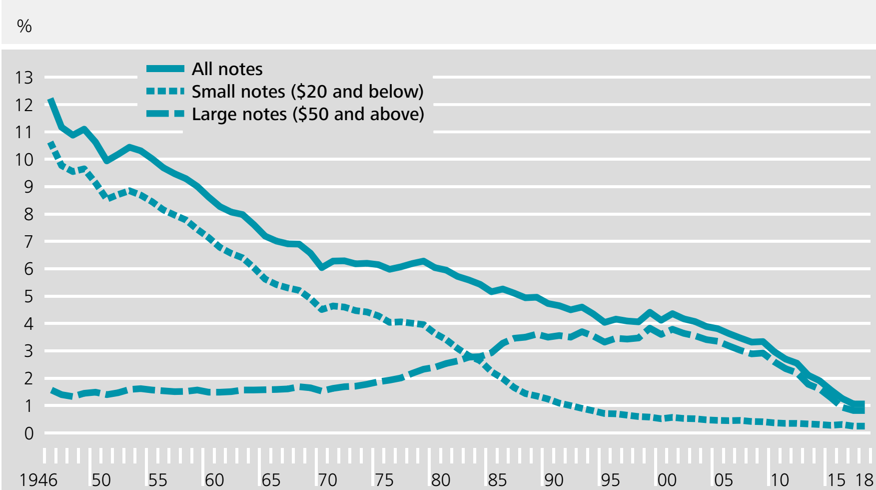
Sources: Bank of International Settlements and authors' calculations.

Large and small denominations as a ratio of GDP in Canada Figure 5a



Sources: Bank of Canada and Statistics Canada.

Large and small denominations as a ratio of GDP in Sweden Figure 5b

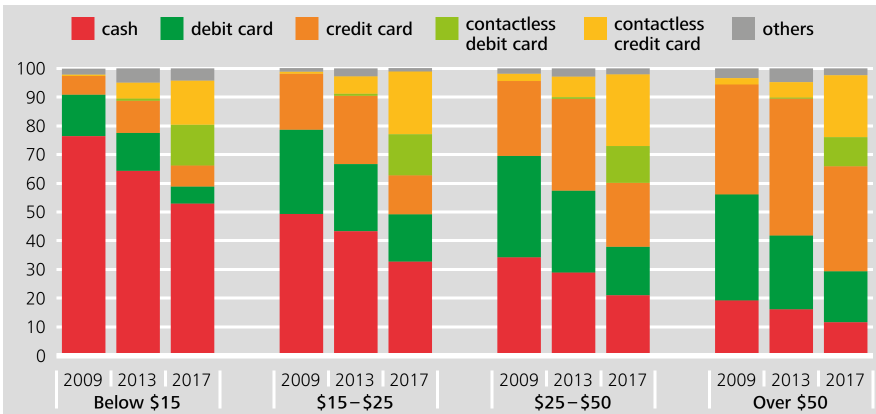


Source: Sveriges Riksbank.

Value share of main payment methods by transaction value in Canada

Figure 6a

%

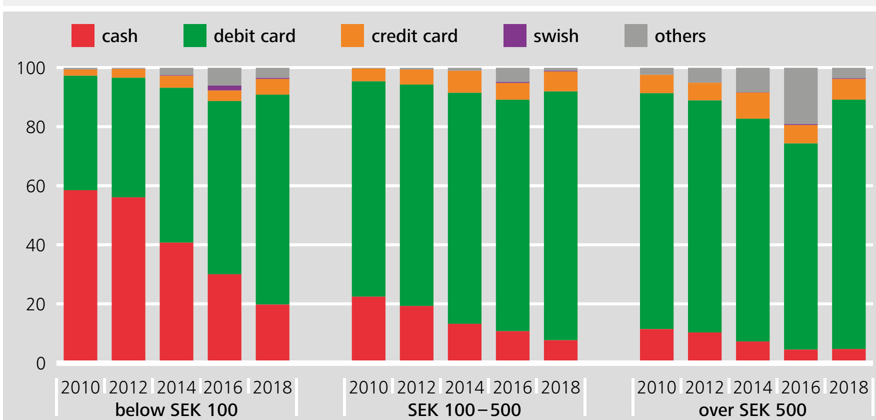


Source: Bank of Canada Methodes-of-Payment surveys, 2009–2017.

The main payment methods for various transaction values in Sweden

Figure 6b

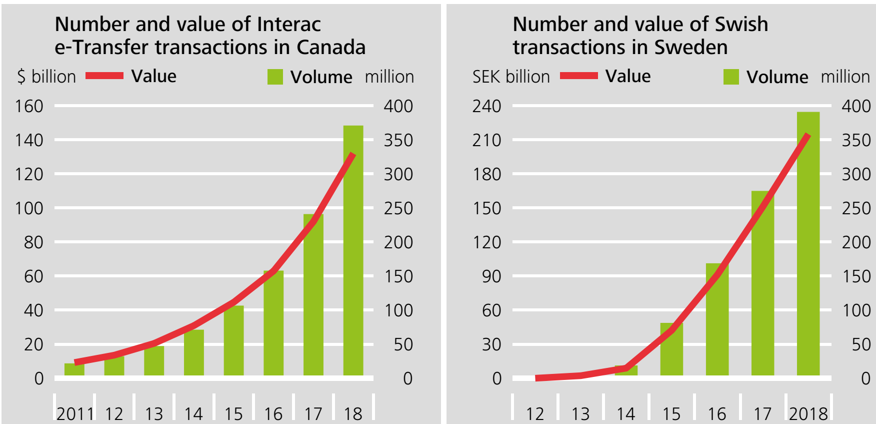
%



Source: Sveriges Riksbank Payment Patterns in Sweden, based on the question "What was your main payment method for payments below SEK 100 (SEK 100–500 and over SEK 500) in a shop over the past month?"

Person-to-person payments: Swish and Interac e-Transfer*

Figure 7



Sources: Swish, Interac. Corp. and Bank for International Settlements. * Notes: The average transaction value of Swish in 2017 was about SEK550 (~CAD50) and the average transaction value of e-Transfer in 2017 was about CAD408.

Bank note series (SEK 20 to SEK 10,000) issued in Sweden from 1894 to 2017

Table 1

	Printed	Invalid after		Printed	Invalid after
SEK 10,000	1939	December 31, 1987	SEK 1,000	1989–1991	December 31, 2013
SEK 1,000	1894–1950	December 31,1987	SEK 50	1996–2003	December 31, 2013
SEK 100	1898–1963	December 31, 1987	SEK 1,000	2006	June 30, 2016
SEK 50	1896–1962	December 31, 1987	SEK 50	2006–2011	June 30, 2016
SEK 10,000	1958	December 31, 1991	SEK 20	1997–2008	June 30, 2016
SEK 500	1985–1986	December 31,1998	SEK 500	2001	June 30, 2017
SEK 100	1965–1985	December 31, 1998	SEK 100	2001	June 30, 2017
SEK 500	1989–2000	December 31, 2005	SEK 1,000	October 1, 2015	
SEK 100	1986–2000	December 31, 2005	SEK 200	October 1,2015	
SEK 20	1991–1995	December 31, 2005	SEK 50	October 1,2015	
			SEK 20	October 1,2015	
			SEK 500	October 2, 2016	
			SEK 100	October 3,2016	

Source: Sveriges Riksbank

Underground economy as a percentage of nominal GDP
(Selected estimates based on the "Multiple Indicators, Multiple Causes" method)

Table 2

	1991	1995	2000	2005	2010	2015
Canada	19.31	16.59	13.40	13.57	10.71	9.42
Sweden	15.54	15.40	12.60	12.32	11.45	11.74

Source: Medina and Schneider (2018), Table A-1

N. Bartzsch, D. Gerdesmeier, B. Landau, G. Maddaloni, G. Rocco, B. Roffia, A. Rua
Forecasting the Demand for Banknotes in the Euro Area[1]

Dieter Gerdesmeier
European Central Bank

Abstract

There are many reasons why central banks need to forecast banknote demand. Among them are the need to predict the production requirements, the need to forecast the autonomous factor position deemed of relevance for the steering of the liquidity position, the need to identify possible risks to price stability in the context of monetary analysis and, finally, the need to monitor developments in the context of early warning indicator for financial risks.

In this study, several approaches are evaluated in terms of their forecasting performance for both individual banknotes' denominations and total currency in circulation.

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1 The views expressed in this study are based on the work also carried out by the authors in the context of the ABCD-2 Workstream of EURECA network of the European System of Central Banks, which was established in October 2017. We would like to thank the participants of the International Cash Conference in Munich for very helpful comments and suggestions and the other ABCD-2 members (Miguel Barcena, Anna-Camilla Drahonsky, Henk Esselink, Laure Lalouette, Guenther Philipp and Ghjuvanni Torre). All remaining errors are of course our responsibility.

The results from the different models based on a pseudo real-time exercise are compared in terms of both visual inspection and statistical analysis of the forecast errors. The models considered in the exercise consist of either simple time series or structural models.

The results suggest that, first of all, most models for individual banknote denominations tend to underestimate the evolution of banknotes' demand over the horizon from one to three years ahead, while for total currency in circulation most structural models tend to over-predict. Second, their forecasting performance tends to vary across models, the forecasting horizon and the banknote denomination. Based on the empirical evidence, it can be concluded that a (small) range of models delivers the most reliable forecasts and, thus, should be considered for forecasting exercises in the spirit of a "thick modelling approach". This notwithstanding, it is concluded that a regular review of the models is warranted. Such an approach is considered to be preferable in order to guarantee the robustness of the results in the context of ongoing structural changes in the economy as well as new developments in financial payments, such as fintech.

1. Introduction

Forecasting currency in circulation is not an easy task. The latter statement holds for several reasons that are related to the underlying factors as well as to possible shocks. The key challenges to producing an effective forecast model are mainly related to, first, the specification challenges with the model itself, second, the inaccuracies in the forecasts for the variables included as explanatory variables and, third, the concerns that past relationships may not hold anymore in the future.

In general terms, the demand for banknotes is determined by their use for transactions, as well as for precautionary and speculative purposes. From an economic perspective, currency demand can be seen as being positively related to transac-

Main motives for holding banknotes

Figure 1

Motive	Determinants	Denominations involved
Domestic transaction	Transactions variables (e.g. disposable income)	mainly small and medium
Domestic store of value	- inflation variability; - interest rate; - tax rate; - probability of detecting tax evasion in different assets; - changes in banking secrecy conditions	mainly large and medium
Non-resident demand	- exchange rate; - trust in local banking sector; - trust in local government	mainly large and medium

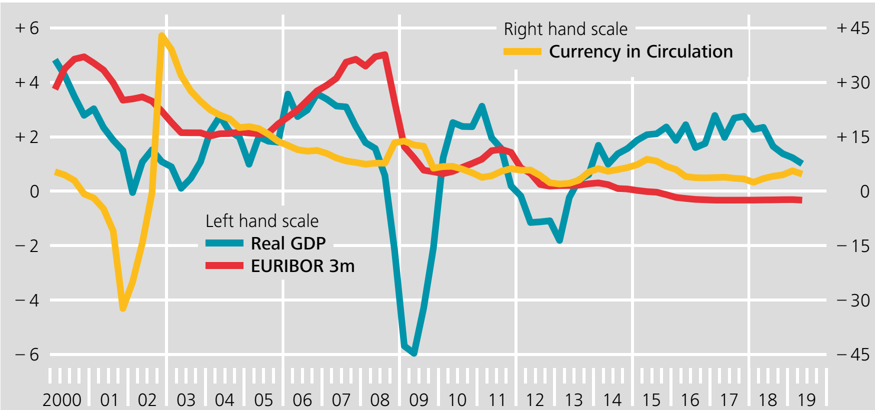
tion variables, such as output, private consumption or retail sales, and negatively related to the opportunity cost of holding currency, such as short-term interest rates measuring the financial return, which could be earned by investing in alternative assets. In addition to these determinants, the demand for currency could depend on other factors, such as the demand for banknotes from abroad, taxes and regulations, the substitution of currency for alternative payment instruments or the shadow economy, which covers a wide range of unreported income, from both legal and illegal activities (see *Figure 1*).

Identifying the exact drivers of currency demand has always been a challenge. *Figure 2* below reports total currency in circulation in the euro area together with some of the domestic determinants mentioned above, which can proxy the transaction motive

Total banknotes in circulation, real GDP and short-term interest rates

Figure 2

annual percentage changes



Sources: Eurostat, ECB and ECB calculations. Latest observation: 2019 Q2.

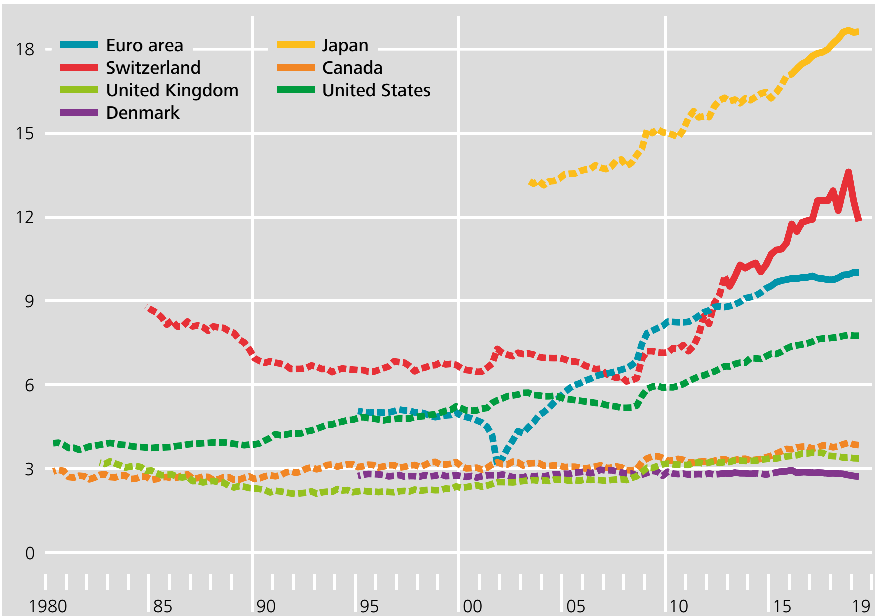
and store of value demand motive. The figure shows that the relationship among all these variables is not always unambiguous. For instance, with respect to real GDP, the correlation is at times quite low, as it happens at the current juncture. Moreover, in times of low interest rates, as in the recent years, there is no clear evidence that currency is increasing faster, as one would expect given the low opportunity costs.

The latter observation also holds when taking an international perspective; indeed, the hypothesis that a major substitution into currency would be induced by the negative rates receives little support. Evidence based on a comparison across jurisdictions of the ratio of banknotes in circulation relative to the size of the economy suggests that, notwithstanding the fact that some countries experienced a pronounced upward trend in the currency-to-GDP ratio for more than a decade, the move to negative rates in some of these jurisdictions has not led to an acceleration in this trend (*Figure 3*).

Currency in circulation outside the banking sector as a share of nominal GDP in the main international jurisdictions

Figure 3

in percentages, quarterly

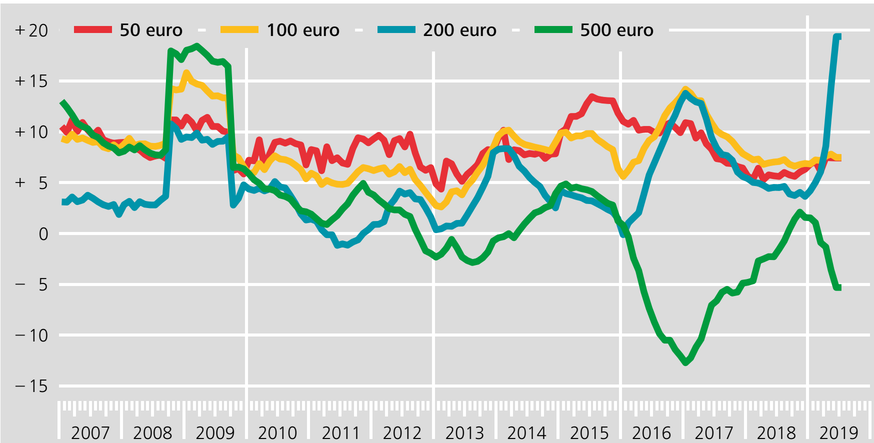


Sources: Bank of England, BIS, ECB, Eurostat, Federal Reserve Bank of St. Louis and OECD. Notes: Dotted lines refer to the periods of non-negative interest rates. Currency in circulation for Switzerland includes Liechtenstein. Latest observation: June 2019.

At the same time, when turning to developments of the individual euro banknote denominations, it is quite evident that forecasting banknotes gets even further complicated as, first, the developments are sometimes characterized by a considerable degree of volatility and, second, some substitution effects across denominations emerge, especially among the high denominations. In particular, the existence of a substitution between the €200 and the €500 notes seems quite striking (*Figure 4*). Taken per se, these dynamics would suggest that a parallel monitoring and forecasting of both individual denominations and overall currency in circulation might

Evolution of individual denominations €50, €100, €200 and €500 Figure 4

annual percentage changes



Sources: Eurostat, ECB and ECB calculations. Latest observation: June 2019.

be preferable. Moreover, when looking at the underlying factors driving banknotes' demand, it has been shown that they may influence individual denominations in different ways. For instance, studies have shown that transaction variables are generally more significant in explaining the demand for low and medium-denomination banknotes, while they do not play a major role in the demand for high-denomination banknotes. By contrast, the latter are used, to a larger extent, as a store of value both domestically and abroad, whereby inflation variability, interest rate developments and the real effective exchange rate of the euro seem to be the dominant factors.[2]

2 Among the studies analyzing the determinants for the demand of low, medium and high-denominations in selected countries, see, for instance: Fischer et al. (2004); Bartzsch et al. (2015); Assenmacher et al. (2017); Flannigan and Parsons (2018), and all related literature reviews contained in these papers.

Second, additional factors enter into play, which are specific to individual currencies, such as cultural issues, exposure to international markets, domestic financial structure, and the national banknote distribution system. As an example of specific factors, with regard to the euro area, some uncertainty stems from the fact that the euro cash changeover in January 2002 triggered an upward structural change in banknote demand.[3] In addition, also the announcement[4] to stop the production of the €500 banknote and to cease issuance as soon as the €100 and €200 banknotes of the Europa series were introduced is very likely to have led to a decline in the volume of €500 banknotes in circulation and a partial shift from €500 into €100 and €200 banknotes in circulation, which has been hard to quantify and forecast (*Figure 4*).[5]

Third, geopolitical uncertainty, the stability of the banking system and the several crises that occurred since 2008 (such as the financial tensions associated with the collapse of Lehman Brothers as well as the sovereign crisis affecting the euro area) are also factors to be taken into consideration when modelling banknotes' demand.

Finally, the foreign demand component is, for some currencies, also a quite important driver of currency in circulation. For instance, as regards the euro, data on net monthly shipments of euro banknotes to destinations outside the euro area point

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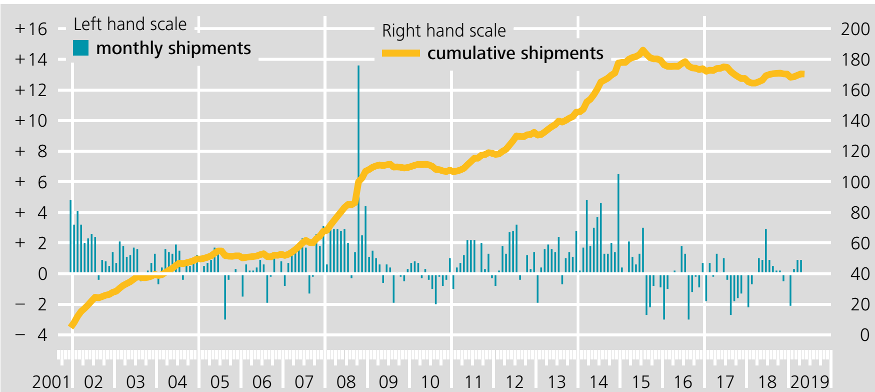
3 In particular, after the euro cash changeover, the use of euro banknotes abroad for travelling and trading purposes is likely to have increased. Increasing expectations in new EU Member States and in accession countries that the euro would have become the domestic currency in the future might have also arisen. Furthermore, a possible substitution of USD banknotes used abroad with euro banknotes could have not been negligible.
4 On 4 May 2016, the ECB's Governing Council announced the decision that the €500 banknote would no longer be issued after the end of 2018. Almost all the Eurosystem's central banks continued to distribute €500 banknotes until 26 January 2019 with the exception of Germany (Deutsche Bundesbank) and Austria (Oesterreichische Nationalbank), which stopped the issuance on 26 April 2019.
5 According to Rua (2019), it is estimated to have had a net impact on the quarter-on-quarter rate of change of the total euro banknotes demand of -0.75 pp in the second quarter of 2016 and -0.5 pp for the subsequent quarters.

Net shipments of euro banknotes to destinations outside the euro area

Figure 5

€ billions; adjusted for seasonal effects



Sources: ECB and ECB calculations. Notes: Net shipments are euro banknotes sent to destinations outside the euro area minus euro banknotes received from outside the euro area. The latest observation refers to May 2019.

to a steady cumulative increase, and a subsequent stabilization in the last few years, of the circulation of euro banknotes abroad (*Figure 5*).

This study is structured as follows. Section 2 describes, from a general perspective, the modelling approaches used by the ECB for forecasting cash demand, while Section 3 sheds more light on the practices which are used in some national central banks (NCBs). A comparison and assessment of these models on the basis of a pseudo real time exercise is illustrated in Section 4, where all the models are evaluated along various dimensions. Finally, Section 5 summarizes the results and draws the main conclusions.

2. Modelling approaches used within the ECB

The forecasts of banknotes' demand must necessarily involve the number of banknotes for each denomination to be printed and to be ready for distribution at specific points in time. Yet, forecasting banknotes' demand remains an inherently complex task. After all, banknotes are anonymous bearer instruments and so many of the sources of demand are difficult to identify and quantify.

As regards the concrete modelling procedure, a number of econometric techniques can be applied, which are described below.

2.1 Time series approaches

A first class of models includes univariate time-series models, such as Auto-Regressive Integrated Moving Average (ARIMA) models, which can be possibly extended with regression variables.[6] ARIMA models have been used in the process of forecasting both individual denominations and total currency in circulation for the euro area. In this context, the ARIMA specifications for the seven euro banknote denominations (€500, €200, €100, €50, €20, €10 and €5) have also included some denomination-specific regression variables, such as those that were designed to capture the extraordinary decline in the demand for banknotes in the run-up to the euro cash changeover in 2002 and intended to include the process of demand in a continuously changing environment, as well as those related to the financial crisis in the late 2000s.

The ARIMA model is specified in terms of the following equation:

$$Y_t=\alpha+\beta_1 Y_{t-1}+\cdots+\beta_p Y_{t-p}+\varepsilon+\theta_1\varepsilon_{t-1}+\cdots+\theta_q\varepsilon_{t-q} \qquad (1)$$

where Y_t is the (quarter-on-quarter) rate of change in (real) currency in circulation.

6 The latter are labelled as "Reg-ARIMA models" in the literature.

The β's and the θ's are the unknown parameters and ε is a random error. In their seminal work, Box and Jenkins (1970) define p as the autoregressive dimension of the model and q as the moving average dimension of the model.[7] Additional information criteria can be applied for the selection of the lags. ARIMA-models are widely regarded as extremely flexible tools for short-term forecasting although, in essence, they just represent sophisticated methods of extrapolation of past developments (in particular, they attribute a somewhat higher weight to the most recent developments of the variable under consideration).

The aforementioned approach suffers from one major caveat. Even if the equations for each individual denomination are arranged in form of a system, the latter will have to be estimated equation by equation. This can be, however, avoided if a Seemingly Unrelated Regression (SUR) model is used. This SUR approach consists of arranging the equations for each individual denominations in form of a system, whereby the regressors on the right-hand-side are allowed to have some common determinants or, alternatively, to be different in each equation. This - in principle - allows treating the demand for individual denominations jointly (instead of individually) and, thereby, allows for possible "spillover" or "substitution" effects. From a purely technical perspective, each equation of the system can then be estimated separately by Ordinary Least Squares (OLS), which can be shown to produce consistent estimates. A special case, however, may arise if the error terms are correlated. However, applying the SUR approach will produce more efficient results.[8] The SUR specifications used in this paper contain lagged terms of the endogenous variables (represented by the individual banknotes' denominations) as well as a dummy for the October 2008 financial crisis.[9]

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7 See Box and Jenkins (1970).
8 See Zellner (1962).
9 This SUR approach differs from the one developed by Banco de Portugal, as it is not characterized by a structural model for each single euro denomination.

It has to be said, however, that all the approaches just described rely on time-invariant coefficients. To the extent that the latter often reflect behavioural changes, this could prove to be a strong assumption. In order to overcome this problem, the Kalman Filter approach can be used. This represents a state-space approach, which can be seen as a generalization of the linear regression model.[10] The key advantage of forecasting aggregate euro banknotes in circulation based on Kalman's "LQE algorithm" is that it relies on a framework, in which coefficients are explicitly allowed to change over time. The equations used in the Kalman procedure are the following:

Signal equation

$$Y_t=\alpha_t+\beta_t\cdot Y_{t-i}+\gamma_t\cdot X_t+\varepsilon \tag{2}$$

State equation

$$\begin{aligned}\alpha_t&=\alpha_{t-1}+\varepsilon_{1t}\\ \beta_t&=\beta_{t-1}+\varepsilon_{2t}\\ \gamma_t&=\gamma_{t-1}+\varepsilon_{3t}\end{aligned} \tag{3}$$

The estimation of the model is then carried out in a two-step procedure, in which, first, estimates for the current state variables are derived, and, subsequently, when a new "measurement" is observed, these estimates are updated (often with larger weight for more recent information).

2.2 Structural approaches

A second class of models is characterised by a multivariate set-up and, in the specific case, was represented by Vector AutoRegression (VAR) and Bayesian VAR speci-

10 The model originally emerged in the engineering literature, where it could be used for instance for the location of satellites. See Kalman (1960) for details.

fications. The so-called Vector AutoRegression (VAR) models avoid the restrictions needed in the traditional macroeconomic models and regard all variables as endogenous.[11] Such models can, in principle, be estimated via OLS or using a Bayesian framework (which then necessitates the specification of a priori information on the distribution of the parameters). VAR-models have also been extended to include exogenous variables. A general formulation of the VAR model (including also exogenous variables) is the following:

$$Y_t = A + B(L)Y_{t-1} + C(L)X_{t-1} + \varepsilon \tag{4}$$

where Y_t is a vector of several endogenous variables measured over the same sample period $t=1,\cdots,T$; A is a vector of absolute terms, B is a matrix of autoregressive coefficients and $\boldsymbol{\varepsilon}$ is a vector of error terms. Exogenous variables X could be included or excluded and they are represented by the $C(L)X_{t-1}$ term. In the basic VAR model, the Y_t vector includes (real) currency in circulation, real GDP, the short-term interest rate and the real effective exchange rate, while the exogenous variables X_t are represented by some dummies related to the euro changeover and the financial crisis as well as by oil prices.

Moreover, this group of models can also contain Bayesian VAR (BVAR) specifications. The background justification for using BVAR models is that VAR models are very flexible statistical models that typically include many free parameters, which could easily lead to the problem of "over-parameterization" (i.e. the fact that such models could easily run out of degrees of freedom). In this respect, Bayesian methods have become an increasingly popular way of dealing with this problem. The basic idea consists in using so-called "informative priors" to "shrink" the unrestricted model towards a more parsimonious benchmark, thereby reducing parameter uncertainty and - at the same time - improving forecast accuracy. In the context

11 See Sims (1980).

of this study, two different types of priors have been used, namely the "Litterman prior" (also known as the "Minnesota prior")[12] and the "Sims and Zha prior".[13]

A final approach considered in the literature, which can be applied to forecasting banknotes in circulation, is represented by the so-called "factor-augmented" VAR (FAVAR) models, which rely on a principal component analysis in order to shrink the parameter space (by identifying common factors from a set of variables). These models can be represented by the following equation:[14]

$$\begin{bmatrix} Y_t \\ F_t \end{bmatrix} = f_1(L)\begin{bmatrix} Y_{t-1} \\ F_{t-1} \end{bmatrix} + \cdots + f_q(L)\begin{bmatrix} Y_{t-q} \\ F_{t-q} \end{bmatrix} + \varepsilon_t \tag{5}$$

where *F* is a *Nx1* vector of factors and *L* are the polynomial lags. It is important to note that the model cannot be estimated directly because the factors are unobservable. These factors, therefore, have to be estimated in a two-step procedure, using a principal component analysis. In the first step, a factor that captures the largest common variation in the set of variables is constructed, while in a second step the FAVAR is estimated by making use of this factor.[15]

Overall, the forecasting framework for euro banknotes which has been used by the ECB in recent years for both individual banknotes' denominations and overall currency in circulation can be summarised as in *Figure 6* below.

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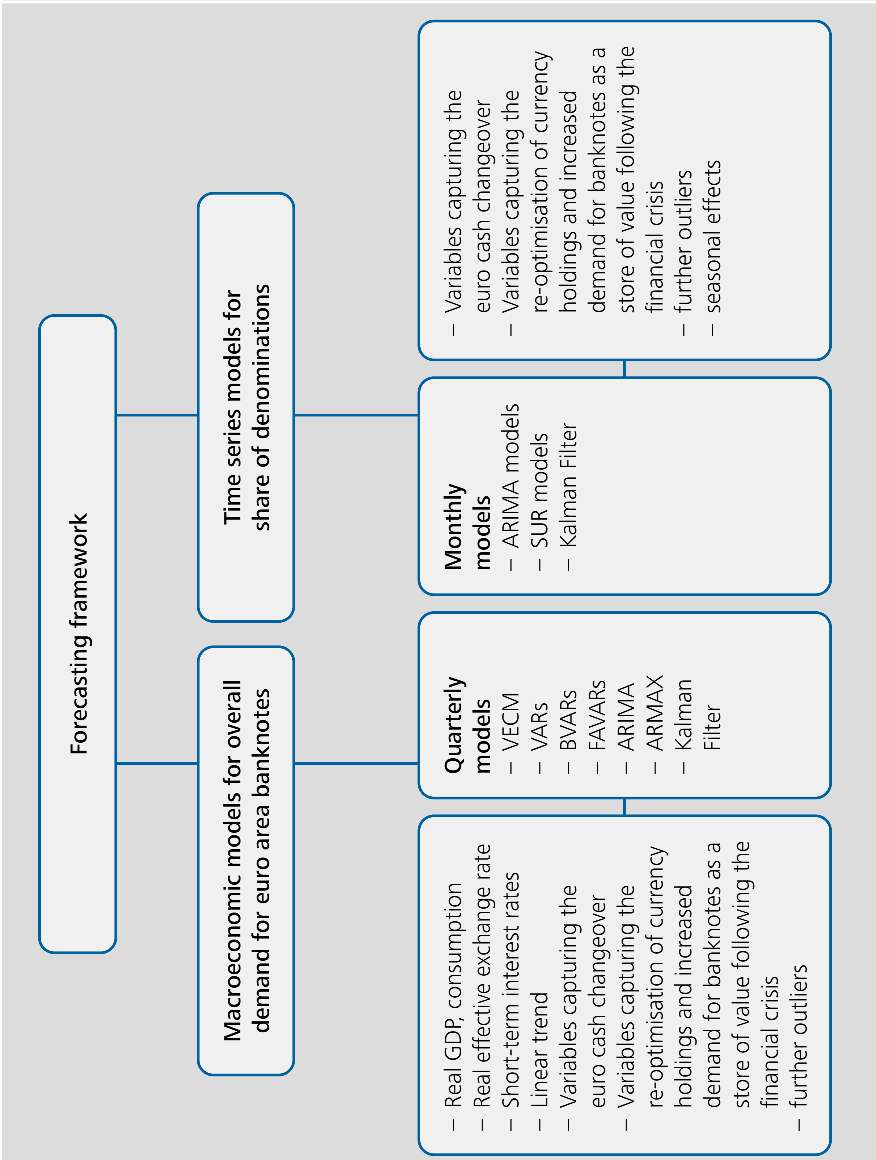
12 See, for instance, Litterman (1979 and 1986).
13 See Sims and Zha (1998). While the "Minnesota prior" involves setting the elements of the parameter-prior and the covariance-prior in a way that is quite realistic from an empirical perspective as it tends to reflect the random-walk behaviour that generally characterizes the level behaviour of many macro-economic variables, the "Sims and Zha prior" relies on a normal flat prior distribution.
14 See, for instance, Bernanke, Boivin and Eliasz (2004).
15 The FAVAR estimated in the context of the forecasting exercise contained the same variables as the VAR and BVAR models.

Forecasting framework for euro banknotes

Figure 6



3. Modelling approaches used within selected National Central Banks

This Section provides an overview of the forecasting methods used by some national central banks (NCBs) in the euro area to determine developments in banknotes in circulation developments in their domestic economy. These methods are, thereafter, compared in Section 4 with those used by the ECB in terms of forecasting performance for individual banknotes and total currency in circulation.

The first framework considered is the one developed by Banca d'Italia. This consists of a routine procedure designed at detecting multiple structural changes within a linear regression framework and; thereby, identifying the "best" forecasting model for the net issuance of each banknote denomination. More precisely, assuming a maximum number of lags for the endogenous variable (for each of the seven individual denominations), the breakpoint regression is estimated in form of a standard multiple regression with an unknown number of potential breaks (to be reflected in a change of the constant). Once the number and the identification of the breakpoints are determined, the model is estimated using OLS. The routine then tests for a finite number of equations, each of which is composed of two blocks: the first block contains the autoregressive terms with dummy variables for special events (e.g. financial crisis of 2008, launch of the second series of the €5, also called "ES2 5"), while the second block refers to different combinations of seasonal dummies. Every time an equation is estimated, additional tests are conducted in order to test the residuals in several respects: (i) for the normal distribution of the residuals (i.e. for a zero mean and a constant variance); (ii) for autocorrelation (by means of a Q-test); and (iii) for normality (using a Jarque-Bera test). The statistical significance of the parameters is also analysed in this context. If one or more models pass the tests, the best performing specification is chosen on the basis of specific statistical forecasting properties, otherwise the choice is based only on the best value of the aforementioned index (in case the hypotheses on the residuals are rejected).

The Banco de Portugal framework basically consists of a macro-econometric model for the demand of euro banknotes issued by the Eurosystem as a whole (considering the full denominational breakdown).[16] This model is coined as the "Demand for Euro Notes" (henceforth “D€NOTES”) model. The framework corresponds to a system of seven equations (one equation for each banknote denomination), whereby the demand for each denomination is described by an Error Correction Model (ECM). The estimation strategy pursued relies on the Dynamic Seemingly Unrelated Regression (DSUR) estimator for the system estimation of the long-run relationships and to a SUR-ECM for the short-run dynamics. Such an approach allows to take the interconnections among denominations into account, both in the short and in the longer run. Several determinants are considered for modelling the demand of euro banknotes, notably the typical motives for cash demand, such as transactions purposes and the store of value motive. The impact of technological developments associated with financial innovation is also taken into account as well as the role played by uncertainty. Moreover, given the well-known international role of the euro, a foreign demand indicator is also proposed. Additionally, special episodes have also been considered, namely the Lehman Brothers collapse in mid-September 2008 and the ECB’s announcement of the end of the issuance of the €500 banknote in May 2016.[17]

A third final framework is the one developed in the Deutsche Bundesbank, which consists of seasonal ARIMAX models for each denomination, which are estimated using monthly data.[18] The models are selected on the basis of the three basic criteria, namely the stability and significance of the coefficients, the goodness of fit and the residuals being uncorrelated. Moreover, the following special effects are taken into account: the escalation of the financial crisis in October 2008 as well

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16 Such a framework was initially applied to Portuguese data, see Rua (2018).
17 For more details on the model and the full estimation results, see Rua (2019).
18 While, in its original form, ARIMA models tend to ignore the role of econometric explanatory variables, more recently, later versions (often labelled as “ARIMAX-models”) have successfully incorporated exogenous variables in the basic specification.

as the decision of ECB Governing Council in May 2016 to stop the production of the €500 banknote. In an additional step, the forecasting performance is analysed each year in order to select the best model. The outcome of the seasonal ARIMAX model is compared with that of three alternative time series models. First, the "constant absolute growth model" (CAG model) is considered, which assumes that the change in the number of notes in circulation in each month is equal to the corresponding change in the same month of the previous year. Second, the "constant growth rate model" (CGR model) is employed, which presumes that the monthly growth rate in the number of notes in circulation in each month is equal to the monthly growth rate in the same month of the previous year. Finally, a Holt-Winters exponential smoothing model with a multiplicative seasonal component is estimated. For each denomination, the root mean squared error (RMSE)[19] of the alternative models turns out to be not significantly lower than the RMSE of the seasonal ARIMAX model, which is, thus, finally selected as the main model.

4. T-Models' forecast evaluation

The forecasting performance of the models presented in Sections 2 and 3 is evaluated on the basis of standard statistical tests using a pseudo real-time exercise.[20] More precisely, the exercise is conducted over a sample period that has not been affected by the ECB's decision on the discontinuation of the €500 banknote issuance in May 2016. This decision was unexpected and, hence, the results based on a more recent sample period would not be informative and could be actually

19 The root-mean-square error (RMSE) is a frequently used measure of the differences between values (sample or population values) predicted by a model or an estimator and the values observed. The RMSE represents the square root of the second sample moment of the differences between predicted values and observed values or the quadratic mean of these differences. These deviations are called *residuals* when the calculations are performed over the data sample that was used for estimation and are called *errors* (or prediction errors) when computed out-of-sample. The RMSE represents a measure of accuracy, to compare forecasting errors of different models for a particular dataset and not between datasets, as it is scale-dependent.

20 See, for instance, Barhoumi et al. (2009).

blurred.[21] The forecast design aims at replicating the real time application of the models as closely as possible: data series as available at the time when the exercise was performed are used for each variable, assuming that no large revisions in the past have occurred in the data (so called pseudo real time exercises).[22] This forecasting exercise is based on a technique in terms of evaluation of the forecast errors, which ensures consistency across the models' forecasts to calculate the main test statistics. In a nutshell, the same number of forecasts for each horizon is derived and this is done by shrinking backward the sample period of the estimations of the models (i.e. the longer the forecast horizon, the shorter the sample period of the estimation), while the starting period of the forecasts remains the same.

There are various types of measures for evaluating the quality of forecasts. Among them, the following criteria were considered in the two exercises:[23]

1. the Mean Percentage Error (MPE), which is derived as the average of the percentage errors calculated between the prediction and the actual value. This measure is used to show under/over-estimation of the forecasts;
2. the Root Mean Square Error (RMSE), which is represented by the root square of the average of the squared differences between predicted and actual values (*see footnote 19*).

As a rule, lower figures indicate a better quality and accuracy of the forecasts for all the measures described above. The forecast evaluation is used to fine-tune the

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21 The main diagnostic tests of the models had already been carried out in the context of their developments by the respective authors.

22 This is true for almost all variables used both in the basket of models and in the ARIMA models (the only exception may be represented by real GDP, although revisions are usually not so significant).

23 Other tests are considered in the literature, such as the Mean Absolute Error (MAE), which is calculated as the average of the absolute differences between the predicted and the actual value; and the Mean Absolute Percentage Error (MAPE), which is represented by the average of the absolute percentage errors calculated between the prediction and the actual value.

current basket of models employed by the ECB as well as to evaluate the selected models developed by the NCBs and a few additional ones proposed in 2019.

The evaluation tests were carried out for the period 2014 Q2-2015 Q4, considering all possible horizons, as the focus of the evaluation was given on the critical horizon of 19 months ahead, which is particularly important in the context of the determination of banknote production. To increase the comparability of the results, it was agreed to start with the estimation of the models from the same starting point, namely in January 2002 or 2002 Q1, depending on the frequency of the data. In order to guarantee the consistency of the number of observations for the forecasts for each horizon, and given that one of models was based on quarterly data, the procedure allows for the possibility to have the same number of forecasts for each horizon and each period for the calculation of the RMSEs and can be summarised as follows (when using monthly data):

– for *t+1* (i.e. one-month ahead), the first estimation period of the models would end in May 2014 and the forecast exercise would start in June 2014, so that the first forecast to be available would be for June 2014. The exercise would then be run in a recursive way by adding one additional actual observation for the estimation of the models till November 2015 (with the last forecast of interest being for December 2015);
– for *t+2* (i.e. two-month ahead), the first estimation period of the models would end in April 2014 and the first forecast observation would cover the sample period from May 2014 to June 2014 to obtain the June 2014 forecast. The second estimation period would end in May 2014 and the resulting forecasts would cover the period June-July 2014 in order to derive the forecast for July 2014. The exercise is carried out in the same way to forecast the following months in a recursive manner by adding one additional actual observation for the estimation of the models till October 2015 (with the last forecast of interest being for December 2015, i.e. the same endpoint as for *t+1*);

– for *t+3* (i.e. three-month ahead), the first estimation period of the models would end in March 2014, and the forecast exercise would be foreseen for the period from April to June 2014 in order to get the first forecast for June 2014, and so on in a recursive manner using data until September 2015 for the estimation of the model to forecast December 2015 (along the same lines of the previous examples);
– this would continue up to the horizon of major focus, i.e. *t+19*, for which the first estimation of the models would end in November 2012, the forecast exercise would start in December 2012 to June 2014, so that the first 19-month ahead forecast would be produced for June 2014 to continue till December 2015.

Thereafter, the RMSEs are calculated considering, for each horizon *t+h*, the forecasts of the annual growth rates produced for the period June 2014 to December 2015, with the procedure guaranteeing that the RMSE is calculated on the same number of forecasts for each horizon (i.e. 19 in total). The same reasoning would apply to the model based on quarterly data, for which, for instance, for *t+1* the estimation of the model would be done over the sample period 2002 Q1-2014 Q1 and the forecasts would be run from 2014 Q2 onwards. In this case, the horizon would comprise the range from *t+1* up to *t+7* (with 7 forecasts available for each horizon in order to derive the RMSEs). As already said, the special focus would be given to the horizons *t+7* and *t+19* for monthly forecasts, and *t+3* and *t+7* for quarterly data. This exercise was run both for the single denomination forecasts and for the aggregate net issuance of currency in circulation.

The forecasts are used to derive the RMSE on the annual growth rates and the MPE on the forecasted net issuance. The MPE helps to recognize if the models lead to an under- or an over-estimation.[24]

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24 No test for statistical significance of the RMSEs is run (such as the Diebold-Mariano) given the small number of forecast values.

As regards the **individual banknote denominations**, the models included in the tests were the following:[25]

- the ARIMA models developed by the Directorate General Monetary Policy (DG-MP) at the ECB and labelled as "**DG-MP ARIMA**" in the previous exercise: "**DG-MP ARIMA 1**" (based on the log transformation) and "**DG-MP ARIMA 2**" *(dlog transformation);*
- the SUR (Seemingly Unrelated Regressions), also developed by the Directorate General Monetary Policy (DG-MP) at the ECB (with *dlog transformation*), labelled as "**DG-MP SUR**";
- the ARIMA models[26] by the Deutsche Bundesbank, which are labelled as "new" because they consist of a re-specification of the ARIMA models developed for the German economy, but using euro area data. These models are either based on *monthly and/or yearly differenced and log-transformed observations or original*, according to the denomination, and they are labelled as "**DE ARIMA new**";
- the routine on breakpoint regression developed by Banca d'Italia, labelled as "**IT ARIMA 1** new" (based on the *log transformation*) and "**IT ARIMA 2 new**" (*dlog transformation*). These specifications are considered as "new" because the number of lags considered for the endogenous variable in the equations for the detection of the best specification has been augmented vis-à-vis the original specification (from 2 to 7);
- the Kalman filter, also developed by the Directorate General Monetary Policy (DG-MP) at the ECB (with *dlog transformation*), labelled as "**KF**";
- the newly developed model by Banco de Portugal, which is based on a SUR-ECM approach, labelled as "**PT SUR**".

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25 In this exercise, for the ARIMA specifications both log transformation and first differences of the endogenous variables were considered in the equations, which resulted in two different versions of the models, which were labelled as "1" and "2".

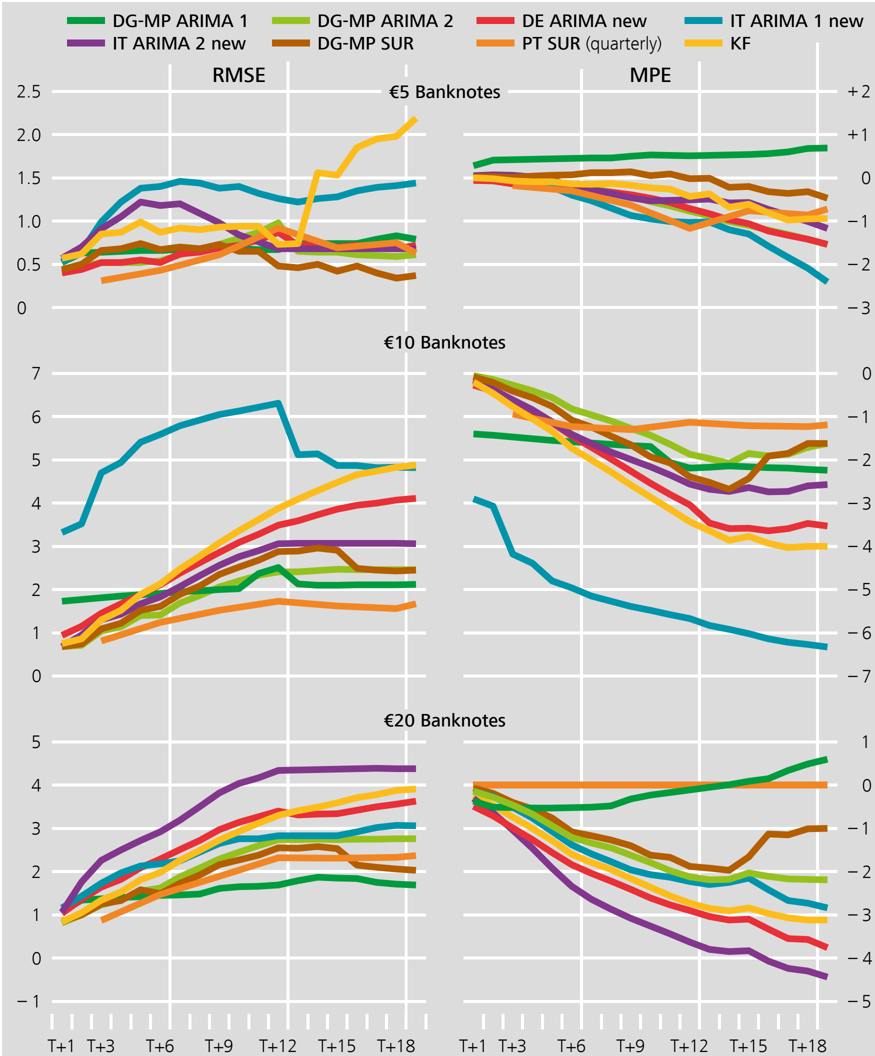
26 These ARIMA models of the Deutsche Bundesbank are newly tested specifications obtained using euro area data.

All the models are based on monthly data apart from the "PT SUR" model, which is based on quarterly data. The outcome of the tests of the models in terms of RMSEs (in terms of values and not as ratios vis-ý-vis a benchmark) and MPEs are reported in *Figure 7* for all horizons from *t+1* to *t+19* and up to *t+7* for quarterly data. It is worth noting that the horizons in terms of quarters coincide with the monthly horizons every three months, so that the last horizon (*t+7*) is in common. The results suggest the following.

- **For the €5 banknote, all models perform quite well approximately until *t+13*** (they all exhibit a RMSE which is lower than 1.6), with the exception of the "IT ARIMA 1 new" model, which has the highest RMSEs up to that horizon. The "PT SUR" performs best for horizons up to *t+9*, whereas for longer horizons the "DG-MP-SUR" outperforms all the models. From *t+14* onwards, the "KF" seems to exhibit a rather explosive behavior, In terms of MPE, all the models underestimate (within a range of -2.5% to 0%) the net issuance (with "DG-MP SUR" being the best), with the exception of the "DG-MP ARIMA 1 new", which overestimates the net issuance for all the horizons even if with a very small error (within a range of 0.25%-0.75%).
- **For the €10 banknote, all models exhibit RMSEs that are higher than those for the €5; however, they also underestimate the net issuance of this denomination, particularly the "IT ARIMA 1 new" model**. In terms of forecasting performance, the "PT SUR" model behaves better than the other models for all horizons (with the MPEs hovering around -1%), followed by the "DG-MP ARIMA 2 new".
- **With regard to the €20 banknote, "DG-MP ARIMA 1 new" is the best performing models in terms of RMSEs over all horizons (except for *t+3* when "PT SUR" has a lower RMSE)**, followed by "PT SUR" and "DG-MP SUR". All the models underestimate the net issuance of this denomination, apart from the "DG-MP ARIMA 1 new", which overestimates the net issuance after *t+15* (its MPE ranging from -1% to 1%).

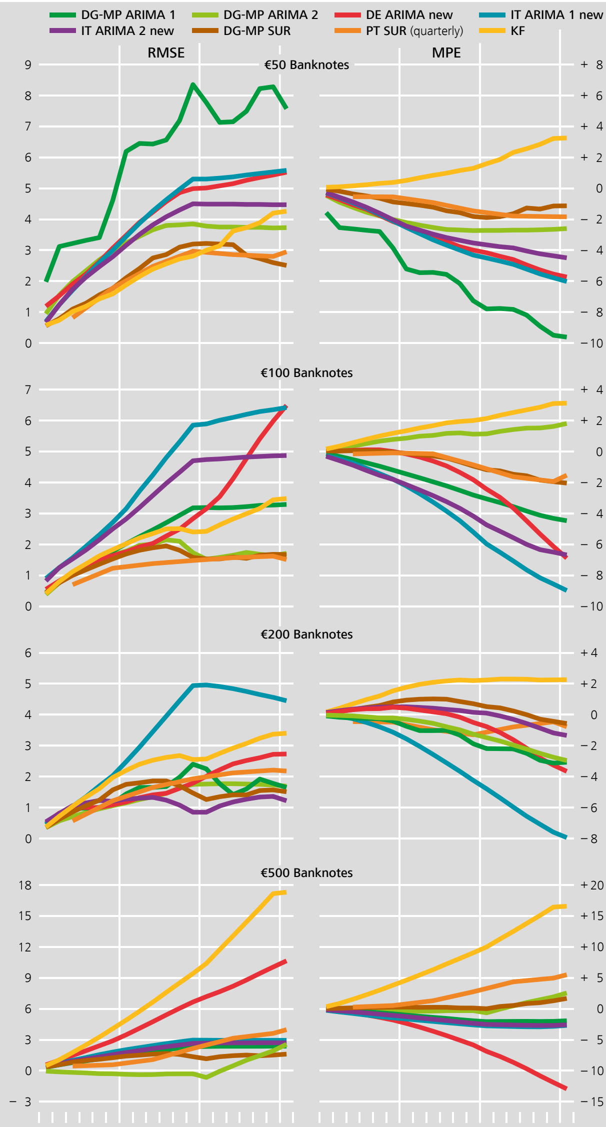
RMSEs and MPEs for individual euro banknote denominations

Figure 7.1



Note: The x-axis denotes the time horizon of the forecasts, ranging from t+1 to t+19 months.

RMSEs and MPEs for individual euro banknote denominations Figure 7.2



Note: The x-axis denotes the time horizon of the forecasts, ranging from t+1 to t+19 months.

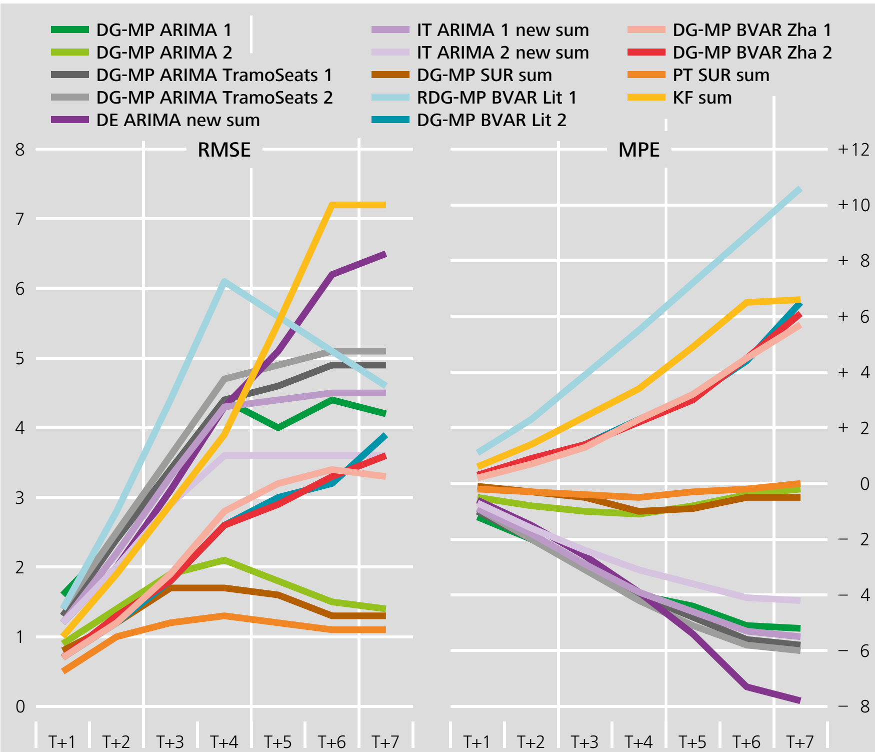
- **"PT SUR" and "DG-MP SUR" models perform best for the €50 banknote, with RMSEs being in line as regards their size to those of the smaller denominations.** At the same time, the "**KF**" exhibit a similar behavior up to *t+14*, but its performance worsens in terms of RMSE at longer horizons. Although, similarly to the case of the previous denominations, all models tend to underestimate the net issuance of this denomination for all the horizons with the exception of "KF", which instead overestimates. "PT SUR" and "DG-MP SUR" models are those which underestimate by a lower amount (their MPEs being between -2% and 0%).
- **For the €100 banknote, the "PT SUR" is the best performing model, and is closely followed by "DG-MP SUR" and "DG-MP ARIMA 2 new", for horizons longer than one year.**
- **As far as the €200 banknotes are concerned, for horizons up to *t+9*, all models behave similarly, with the exception of the "IT ARIMA 1 new", which performs much worse than the others.** For horizons longer than *t+10*, "DG-MP SUR" and "IT ARIMA 2 new" models are the best performing ones, although they tend to slightly overestimate till *t+16* and *t+13*, respectively.
- **Finally, as for the €500 banknotes, the "PT SUR" is the best performing model for horizon up to *t+9*, while for longer horizons the "DG-MP SUR" turns out to be the best model (with some slight over-predictions from *t+14* onwards).**

As regards **total currency in circulation**, the models included in the tests were the following.

- the ARIMA models based on TramoSeats, labelled as "**DG-MP ARIMA TramoSeats 1**" (*log transformation*) and "**DG-MP ARIMA TramoSeats 2**" (*dlog transformation*);
- the different BVAR models developed by DG-MP with different prior specifications and change or levels as variables of interest and included in the basked of models in the context of the ABCD yearly exercise, labelled as "**DG-MP BVAR**

RMSEs and MPEs for total currency in circulation

Figure 8



Note: The x-axis denotes the time horizon of the forecasts, ranging from t+1 to t+7 quarters.

Lit 1" and "**DG-MP BVAR Zha 1**" (*log levels*) and "**DG-MP BVAR Lit 2**" and "**DG-MP BVAR Zha 2**" (*dlog transformations*);

– the **sum of the forecasts for individual denominations** obtained above, which are denoted with their name plus the suffix "**sum**".

All the models are evaluated on a quarterly frequency. *Figure 8* reports the relevant statistics for total currency in circulation. In line with the outcome of the exercise for the individual banknotes, the “PT SUR sum” model performs best for all horizons, followed by the “DG-MP SUR sum” and the “DG-MP ARIMA 2”. For these models, the forecast errors turn out to be quite negligible, with an MPE close to zero. At the same time, the other model classes also perform relatively well.

5. Conclusions

This paper focuses on assessing the forecasting performance of several models for euro banknotes, which had been developed either by staff at the Directorate General Monetary Policy at the ECB or by NCBs. These models were based both on statistical techniques and on structural models. The assessment was carried out via statistical tests and visual inspection in the sample period 2014 Q2-2015 Q4.

Overall, the results reveal that no single model or model class performs best over all denominations and horizons. Nevertheless, the SUR models developed by the ECB and one NCB (Banco de Portugal) seem to perform best, with their forecast errors turning out to be quite negligible. In addition, also some of the ARIMA models developed by the ECB perform quite well over the most recent period, particularly those for individual denominations. This suggests that good results could be achieved when forecasting individual denominations and then summing them up to arrive at an aggregate forecast, particularly once the interaction between the various individual denominations are taken account of. Interestingly, macro-economic models or more statistical time series models, as long as well specified, possess relatively similar overall forecasting performance over the period considered. Furthermore, the exercise suggests that different models have different performance over the various horizons. However, when concentrating on the most important horizon, namely *t+19*, the two models developed by the ECB and Banco de Portugal perform quite well.

The results are promising and would suggest using a small basket of models for forecasting banknotes in circulation to ensure a robust input into the banknotes' production planning, instead of using only one approach (i.e. ARIMA). Following a "thick-modelling approach", a central forecast as well as lower and upper bounds would be derived and used as input for the yearly production requirements exercise. Therefore, on the basis of the results illustrated in Section 4 and notwithstanding the better performance (although with a general underestimation for the individual denominations over all periods) of a couple of models in forecasting the net issuance of banknotes, and taking into account the need to avoid the risk of a systemic underestimation, it seems plausible that working with a combination of a small set of approaches for individual banknote denominations, and to complement them with an expert judgement would be preferable. This approach ensures robustness by using models based on different approaches (time series and structural models) and, thereby, hedging against uncertainties and possible changes in drivers and model specifications.

At the same time, continuous improvements should be sought and implemented especially regarding the inclusion of additional variables to take into account the increasing foreign demand and financial innovation such as cashless payments or digital money. In addition to this, also the discontinuation of the issuance of the €500 banknote represents a challenge for the modelling framework, as the latter remains legal tender and can, therefore, continue to be used as a means of payment and store of value and substitution effects vis-à-vis other large denominations, such as €100 and €200, can still be expected.

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Cash Use Across Countries and the Demand for Central Bank Digital Currency

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International Monetary Fund (IMF)

Abstract

Within any country, the demand for central bank digital currency (CBDC) will be influenced by trends in the level of cash use. While having access to digital currency is more convenient than having to travel to an automated teller machine, this only makes digital currency as convenient as a bank debit card–not better. Demand for digital currency will thus be weak in countries where the adoption of cash substitutes (eg cards, electronic money, mobile phone payments) has suppressed demand for cash. By contrast, where cash use is high due to a lack of substitutes, demand for digital currency should be stronger. Building on the observation that demand for CBDC is tied to the current level of cash use, this paper uses four measures to assess trends in the demand for cash in 11 countries. A tentative forecast of cash use is also made. After showing that declining cash use is largely associated with demographic change, the study ties the level of cash use to the likely demand for CBDC in different countries. In this process, it is suggested that one measure of cash use is more useful than the others.

1. Introduction

In many developed countries, the use of physical cash is falling; indeed, in some it is already quite low. One such country is Sweden, where the share of cash payments in retail transactions fell from 40 per cent in 2010 to 15 per cent in 2016. In 2017, a survey found that two-thirds of Swedish consumers believed they could get by without cash.[1] Instead of cash, Swedish consumers are using cards, electronic money, and Swish–a system that links a consumer's mobile phone to their bank account.

In response, some central banks are investigating the possibility of issuing digital currency as a future replacement for cash, while one country is considering a pilot programme to determine how central bank digital currency (CBDC) would operate if adopted. In what follows, this paper will refer to central bank digital currency as 'CBDC', or simply 'digital cash', and use 'cash' to represent physical cash or currency currently in use.

To gauge the present level of cash use and how quickly it may be falling, this study estimates the use of physical currency in 11 countries for the period from 2006 to 2016, and forecasts how this could change over the next 5–10 years. The estimates of current cash use are based on simple indirect and direct calculations fitted with a cubic spline (similar to a moving average). Logistic curves, such as are used to forecast the adoption of robots in manufacturing, are applied to forecast cash share going forward.

To date, the discussion regarding digital cash has chiefly centred on supply-side concerns–the benefits of digital cash, why it may be needed, how it could be structured, and the possible implications for monetary policy or financial stability.[2]

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1 Sveriges Riksbank (2017) 'The Riksbank's E-krona Project', Report 1, September.
2 Committee on Payments and Market Infrastructures and Markets Committee (2018) 'Central Bank Digital Currencies', Bank for International Settlements, Basel.

Were digital cash to be implemented, however, its success would naturally depend on the demand for it, which is the focus of this paper. Demand for digital currency largely depends on a country's current level of cash use and how quickly that may be falling. In turn, this depends on the cost and convenience of CBDC for potential users relative to the payment instruments that have already replaced many cash transactions in some countries.

The following section describes cash usage in 11 countries (Australia, China, Denmark, Germany, India, Japan, Netherlands, Norway, Singapore, the UK and the USA) between 2006 and 2016. The sole criterion for selecting these countries was data availability. Unfortunately, Sweden is not part of our sample as we were unable to find information on the value of cash withdrawals over the counter at banks.

The paper compares four ways to illustrate cash use. It then provides a simple explanation for why cash use has been falling, before forecasting cash use over the next 5–10 years. Following this, the paper discusses why demand for CBDC will likely be weak for some countries but stronger in others. The final section concludes.

2. Current use of cash

What is the best way to measure cash use in a country? If the value of cash expenditures is known, cash use can be measured on a per person basis or as ratio to gross domestic product (GDP), household consumption or cash expenditures plus the value of other payment instruments that commonly substitute for cash (ie the market for cash). The trend or *change* in cash use can be determined with any or all of these four alternatives. Even though the numerator (the value of cash expenditures) may be the same, the *level* of cash use will differ as there would be four different numeraires. The numeraire in the market for cash is the only measure to reflect why cash use may be rising or falling; the others are all silent. While this measure is arguably best as it contains the most information, the paper will illustrate three other measures for comparison.[3]

The information needed to show how cash use varies over time is all contained in a simple equation: $S_t = \alpha + \beta t$. Here, S_t is the share of cash payments in a country (however measured); α is an intercept; β is a slope; while t is time (eg 2006, 2007, … , 2016). All variables that influence the *level* of cash use will be reflected in α (the intercept). This could include a country's acceptance of technical change (reflecting culture), the development of and trust in the banking system, and past availability of newer electronic payment methods. Although interesting, there is no need to know why α is high for Germany but low for Norway. Everything that affects the level of cash use is already reflected in α, although it remains unidentified. The same is true for β (the slope). This reflects all the variables that affect the change in cash use, such as how quickly newer or more convenient or lower-cost payment instruments are replacing cash in a country.

2.1. Currency in circulation to GDP

A common way to express cash use is to compute the ratio of currency in circulation (CIC) to nominal GDP. *Figure 1* provides this information for all 11 countries. The figures measure data in billions of purchasing power parity adjusted US dollars. *Figure 1A* shows the CIC/GDP ratio for the five countries in Asia while *Figure 1B* shows the ratio for the other six countries. The computed cash use data are annual

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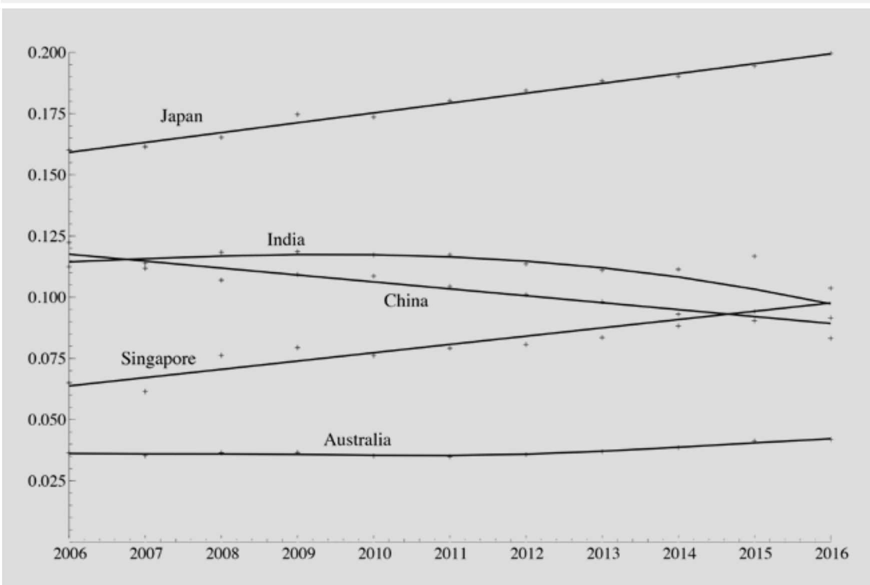
3 A more common comparison may help. Beef consumption in a country can be measured by the value of beef consumed to GDP, to population, or to the market for meat. All three will reflect the trend in beef consumption. However the measured level of beef consumption will differ: it will appear low relative to GDP but high relative to the smaller value of the market for meat. Beef consumption to GDP will not be a good comparison across countries as GDP can vary independently from the demand for beef. Beef consumption per person is better. Although culture and tastes differ across countries, it does not change much over time. However, only when considering the market for meat – not just beef–will it be obvious why beef consumption may be changing. Here, the measure (beef consumption)/(beef + chicken + pork + lamb + etc) has more information regarding beef consumption as it shows what is substituting for beef or vice versa.

observations fitted using a cubic spline. Only in three of the 11 countries is cash use falling, namely India, China and Norway. The other eight countries either show increasing cash use (Japan, Singapore, Germany, Netherlands, USA and UK) or approximately no change (Australia and Denmark). Similar results were obtained using many more countries, especially emerging market economies.[4]

The assumption underlying the CIC/GDP ratio is that currency in circulation reflects cash use in a country. However, the use of cash is a flow of spending while CIC is the

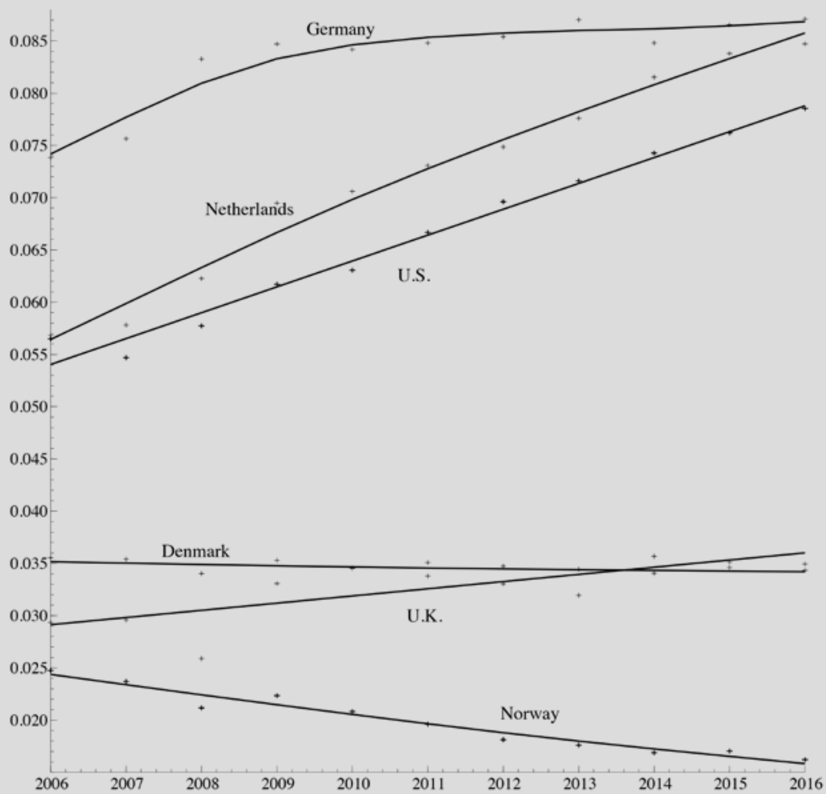
Currency in Circulation to GDP, 2006-2016 Figure 1A



4 Bech, M., Faruqui, U., Ougaard, F. and Picillo, C. (2018) 'Payments are a-changin' but cash still rules', BIS Quarterly Review, March, pp. 67–80.

Currency in Circulation to GDP, 2006-2016

Figure 1B



stock of currency used for spending. To be comparable across countries, the turnover ratio of this stock should be similar across countries.[5] In addition, only the consumption component of GDP, and even then only the lower-valued consumption goods and services that are commonly purchased with cash and cash substitutes, should be in the denominator. For this reason, the ratio of CIC to GDP is not relied upon here. However, it is often used because data on CIC and GDP are easily available.

This measure could be more useful if, instead of GDP, the denominator reflected only the value of consumption goods that cash is commonly used to purchase, but this information is much more difficult to obtain. There is more information on payment instruments that substitute for cash than on cash itself. This leads to the following alternative measure of cash use.

2.2. Cash use measured as a residual

It is possible to approximate cash use by selecting the components of GDP where cash is commonly used in transactions (such as the value of household consumption) and subtracting the value of non-cash payment instruments also used for consumption. Here, cash is measured as a residual. The share of cash in transactions is obtained by dividing this cash estimate by the value of household consumption: RESIDUALHC = (HC − CARD − E-MONEY)/HC where HC is the value of household consumption in the national accounts; CARD is the value of all debit and credit card payments; and E-MONEY is the value of private stored value cards or mobile phones used in consumption transactions.

5 Our view is that the value of all cash withdrawn from ATMs and over the counter at banks (call this W) is a direct and, at least currently, the most accurate indicator of cash use in a country. For CIC to be a similarly good indicator of cash use, the turnover ratio of the flow of cash being spent relative to the stock of currency (k = W/CIC) requires that k and the proportion of cash held idle at banks or central banks, are similar across countries (which has not been demonstrated).

The residual approach relies upon knowing and subtracting all non-cash payments for consumption goods and services whether or not they substitute for cash.[6] However, data on the value of cheques, automated clearinghouse (ACH) or giro transactions, and instant payments that are used only in consumption transactions are unavailable. Data on the total value of cheque, ACH, giro and instant payments in a country are commonly available, but never the value used only for consumption. The result is that this measure will overstate the level of cash use.

The residual approach suggests that cash use has fallen, at times quite significantly (values in the text for this measure exclude China as the data indicate an impossible reduction in cash use of over 100 per cent, indicating a problem with the data). In 2016, the highest share of cash use in household consumption was 84 per cent for Germany, followed by 82 per cent for Japan, while the lowest was 31 per cent for the UK, followed by 39 per cent for Norway. The average percentage point (pp) reduction in the computed shares shown for ten countries was 13.3 pp, or 1.3 pp per year over ten years.

2.3. Share of cash withdrawals in household consumption

A more direct method of estimating cash use would be to determine the value of total sales of consumption goods commonly made with cash. If it is assumed that the cash withdrawn from ATMs and over the counter (OTC) at banks in a country is almost all spent on household consumption items, this value can be related to the value of household consumption in: CASHHC = (ATM + OTC cash)/HC. The value of cash withdrawn from ATMs and banks is effectively equivalent to the value of cash

6 With central bank assistance, and access to detailed data on household consumption, it was possible to properly compute the residual approach in an earlier study of cash use in Norway; see: Humphrey, D., Kaloudis, A. and Owre, G. (2004) 'The future of cash: falling legal use and implications for government policy', Journal of International Financial Markets, Institutions and Money, Vol. 14, pp. 221–233.

used from a national-level payment diary for all consumers.[7] The results for China and India show a rise in cash use while the other nine countries show a reduction. The highest share of cash use in 2016 was 36 per cent for Germany, followed by 24 per cent for Singapore, while the lowest was 6 per cent for Japan, followed by 7 per cent for Norway.

These shares are lower than those of the residual method (due to the use of a smaller numerator). Even so, the average reduction in cash use across the countries (excluding China and India) was 1.4 pp per year, which is very close to the annual 1.3 pp reduction found for the residual method. This suggests that the different estimated levels of cash use (the intercept) have little effect on the slope providing the trend in the use of cash across countries.

2.4. Share of cash withdrawals in the market for cash

The share of cash used in the market for cash is the value of cash withdrawals as a percentage of the value of transactions made using these withdrawals plus two of the currently strongest substitutes for cash–cards and e-money: CASHSHARE = (ATM + OTC cash)/(ATM + OTC cash + CARD + E-MONEY). The numerator is the same as the prior measure but the denominator is smaller as the focus is on cash and cash substitutes, which comprise the effective market for cash, as opposed to the value of all consumption. However, there remains a problem with the data. The denominator should include the value of cheque, ACH,

7 Cash withdrawal data were obtained with assistance from certain central banks and from the Payments.com (2018) 'Global Cash Index' Asia-Pacific Edition (June), Australia Edition (July), India Edition (August); and Payments.com (2017) 'Global Cash Index' United States Analysis (March); United Kingdom Edition (November); Germany Edition (December). This measure does not include cashback at the POS and there is no information on the value of cash withdrawn and held idle for hoarding or precautionary purposes. Even so, the year-to-year variation here should normally be small so the slope should not be much affected. For more information on the data used and the results, see: Khiaonarong, T. and Humphrey, D. (2019) 'Cash use across countries and the demand for central bank digital currency', IMF Working Paper WP/19/46, International Monetary Fund, February. The appendix to this paper lists the sources for all figures and tables shown here.

giro and instant payments that currently commonly substitute for cash in consumption.[8] Fortunately, in many developed countries this value is believed to be small–for example, automotive purchases, utility bills, insurance payments and large purchases at supermarkets are not commonly paid in cash; neither are large-value purchases such as furniture, clothing or appliances.

This measure has the fewest data problems, reflects what is substituting for cash and making it fall, and thus is the preferred measure for the present study. In practice, if all that is desired is to obtain a good idea of the trend (not the level) of cash use in a country, any of the last three measures could do this (although some more accurately than others). The results are shown in *Figures 2A* and *2B*. All but India show a decline in the use of cash over the period. In the latter case, however, the data include the disruption due to demonetisation in 2016.

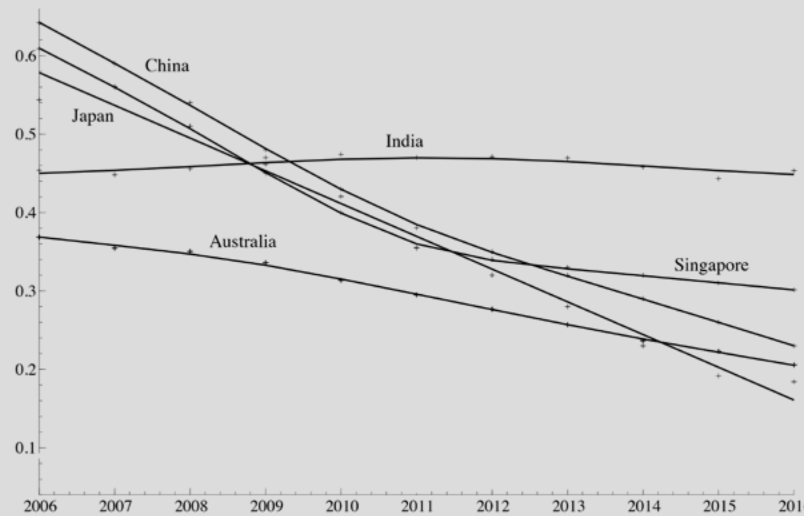
To summarise the results, the intercepts–the cash share levels–are mismeasured to differing degrees due to missing data. The mismeasurement is smallest for the share of cash withdrawals in the market for cash. Overall, the mismeasurement seems to have little effect on the estimated trend in cash use. The trend in cash use indicated by the slope (bottom row of *Table 1*) suggests that from 2006 to 2016, cash use across the sample countries fell by an average of 1.3 pp, 1.4 pp and 2.2 pp per year, respectively, for the three most useful measures. Thus, the average reduction in cash use is quite similar: between 1.3 and 2.2 pp a year.

This suggests that the driving force behind the reduction in cash use across countries is similar and, as suggested below, may be related to demographic change. However, this does not mean that the percentage changes will be similar across

8 Again, we know the total value of cheque, ACH, giro and instant payments in a country, but not the (smaller) value used only for consumption, nor the (much, much smaller) value that commonly substitutes for cash in consumption.

Share of Cash in Cash, Card, and E-Money Transaction Value, 2006-2016 Figure 2A

Cash = ATM + OTC Withdrawals

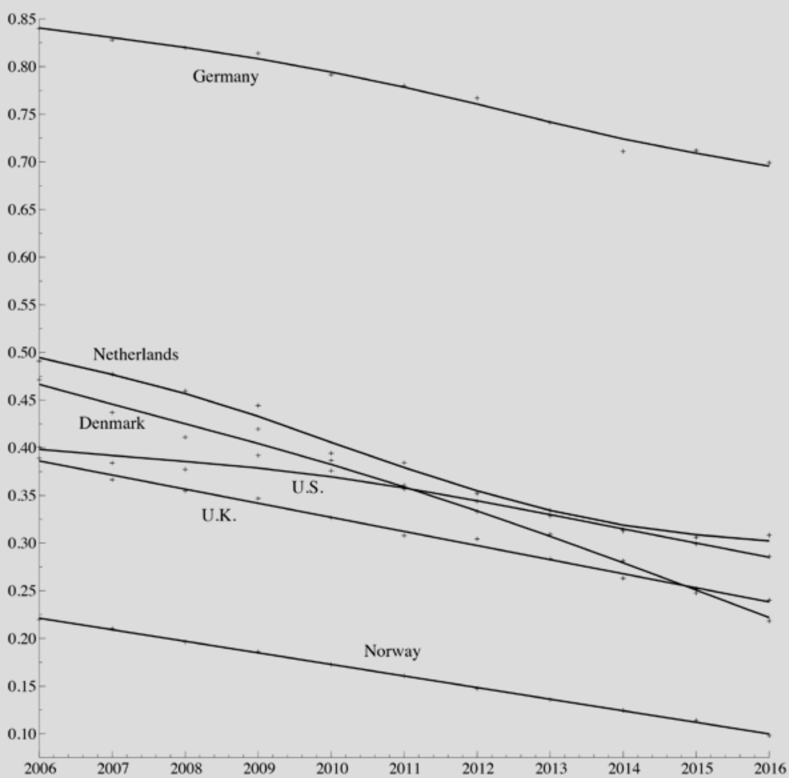


countries as the bases for the percentage point changes–the levels of cash use across countries–can be quite different. For example, a 1.4 pp annual reduction in cash use for Germany, based on the average cash-use levels of 77 per cent observed in 2006 and 2016, provides a change of 1.8 per cent, which is significantly different from the case in Norway, where a similarly small 1.2 pp change from an average base of 16 per cent provides a 7.5 per cent change.

For the preferred measure (CASHSHARE), the second to last column in *Table 1* shows the level of cash use for 2006 (in parenthesis) and 2016. The highest level of cash use in 2016 was 70 per cent for Germany (followed by 45 per cent for India), while the lowest was 10 per cent for Norway (followed by 23 per cent for Japan). In countries where payment systems are less well developed and cash substitutes are limited, there would be a greater level of cash use than in many of the countries shown here.

Share of Cash in Cash, Card, and E-Money Transaction Value, 2006-2016
Cash = ATM + OTC Withdrawals

Figure 2B



Reductions in Cash Use Over 2006-2016 Table 1

	RESIDUAL/HC Annual Change pp	CASH/HC Annual Change pp	CASHSHARE Annual Change pp	CASHSHARE Level in (2006) and in 2016	CASHSHARE Annual Change %
Australia	1.2	1.1	1.6	(37) 21	6
China	17.1	-1.6	3.6	(54) 18	10
Denmark	1.0	2.2	2.5	(47) 22	7
Germany	0.4	1.5	1.4	(84) 70	2
India	2.0	-1.7	0.0	(45) 45	0
Japan	0.6	1.5	4.1	(64) 23	9
Netherlands	1.3	0.9	1.8	(49) 31	5
Norway	0.6	0.9	1.2	(22) 10	8
Singapore	1.5	4.0	3.1	(61) 30	7
U.K.	3.3	0.5	1.5	(39) 24	5
U.S.	1.4	0.3	1.1	(40) 29	3
Average	**1.3**	**1.4**	**2.2**	**(49) 29**	**6**

Note: Numbers in the table have been rounded off. Cash use results for China and India would appear to have problems that this study has not resolved. For this reason, the computed percentage point changes shown in the table exclude the greater than a 100 per cent reduction in cash use for China, negative values (rising cash use) for China and India, and no net change in cash use for India in, respectively, the three cash use measures shown.

The average percentage point changes for the CASHSHARE measure are shown in the third to last column in *Table 1*. Taking Australia as an example, the cash use reduction in percentage points averaged 1.6 pp over 2006–2016. Expressing this change as a percentage of the average base for Australia of 29 per cent (computed from (37 + 21)/2), the average percentage reduction over this period was 6 per cent each year. As seen in the last column, the percentage reduction in cash use fell faster in China, Denmark, Japan, Norway and Singapore, than in Australia (which is the same as the overall average). Cash use in Germany, Netherlands, the UK and the USA fell at a slower rate, while for India it did not fall at all.

3. Why has cash been falling?

How well does the passage of time (t) explain the variation in the share of cash use (S_t)? As seen from the graphs in *Figure 2*, many of the plotted cash shares for the preferred measure (CASHSHARE) are almost straight lines. The passage of time over 2006–2016 is also a straight line (1, 2, 3, … , 11). In the simple regression $S_t = \alpha + \beta t$, the R^2 values are 0.89 for India and Singapore, 0.94 for the USA, and between 0.97 and 1.00 for the remaining nine countries. Thus, even though the sample size is small, the fit is quite high. There is not much left over to be explained by additional variables affecting cash use. Even so, changes in interest rates or the adoption of new laws or regulations may have been important in some countries.

Surveys show that younger adults use cards and mobile phones to make payments more often than older adults, and consequently use less cash. The average (live) birth rate across the 11 countries sampled here is 1.2 per cent per annum, while the average death rate is 0.8 per cent. As younger adults enter the population (equal to the birth rate) and older adults leave it (equal to the death rate), the average composition of the population changes by 2.0 per cent per annum. In 2006, this change is thus 2.0 per cent relative to 2005. The change in population composition by 2007, relative to 2005, is 4.0 per cent. By 2008, the change in population composition is 6.0 per cent and so on up to 2016, where the cumulative change is 22 per cent.

Although birth and death rates do change slowly over long periods, the present paper assumes that these values remained constant for the duration of the study period, as this was more or less the case for most of the countries covered. Thus, demographic change (assumed to be a constant C = 2.0 per cent each year) is $C \times 1$ for 2006, $C \times 2$ for 2007, and so on. Over 11 years it forms the sequence $C \times (1, 2, 3, \dots, 11)$, which is a linear series like time 1, 2, 3, … , 11. For individual countries, the sum of the birth rate and death rate ranged from 1.3 per cent in 2006 (Singapore) to 2.6 per cent (India). For both Denmark and Norway it was 2.0 per cent in 2006. The cross-country average was 1.98 per cent for 2006, which rounds to 2.0 per cent.

Demographic change over all 11 countries, as well as for each country individually, is a linear series. As both time and the sum of the birth and death rates both form a linear series, the result from running $S_t = \alpha + \beta$ (birth rate + death rate) for each country gives the same high R^2 values as achieved using time (t) above. While any linear series regressed on St would give the same strong fit, the demographic explanation presented here is supported by two facts. First, surveys show that young adults use more cash substitutes and less cash compared with older adults. Secondly, the change in the composition of the population–new entrants plus new exits–both work in the same direction to decrease the use of cash in a country, although the rate of change varies across countries.

4. Forecasting cash use

It is reasonable to expect that a plot of annual observations on cash use over time–if long enough–would look something like a reverse Gompertz S-curve. That is, cash use would fall initially, gather speed, reach an inflection point and then start to fall at a decreasing rate until cash use was very small. Logistic and Gompertz growth or S-curves have been used in a variety of situations to forecast the adoption and dispersion of new technologies in industry and consumption (eg the adoption of telephones and televisions) and can be adapted to forecast the possible future use of cash.

It is worth noting that in a detailed empirical comparison, Meade and Islam have shown that the standard logistic and Gompertz S-curves outperform more complicated models.[9] This is largely because more complicated models have more parameters to estimate and the data available typically cannot support the increased complexity.

4.1. S-curve forecast model

A standard Gompertz S-curve model would be $\ln (S_t / (1 - S_t)) = \alpha + \beta t + e_t$ where, for example, S_t is the share of electronic payments in a country and β is the coefficient of diffusion or the slope of the S-curve. In this case, the St for retail electronic payments is expected to rise over time (t) first slowly, then gathering speed with greater adoption of electronic payment alternatives. At some point it reaches an inflection point and instead of continuing to rise at an increasing rate, rises at a decreasing rate until the market is saturated (here, it is worth noting that saturation need not be 100 per cent. For example, in the USA, the saturation point for black-and-white televisions was close to 100 per cent; for basic cable television, it was only about 65 per cent; while for satellite television it was little more than 25 per cent).

It is expected that the S-curve for the use of cash over time will be the reverse of the adoption of retail electronic payments as one basically substitutes for the other. As the share of cash is expected to fall, rather than rise, the dependent variable in the equation using St in the electronic payment application is reversed. The dependent variable in the estimated logistic curve (1) has been altered to show a falling cash payment share (S_t) as a function of time over 2006–2016. The estimated parameters have the same interpretation:

$$\ln ((1 - S_t)/S_t) = \alpha + \beta t + e_t. \quad (1)$$

9 Meade, N. and Islam, T. (1995) 'Forecasting with growth curves: an empirical comparison', International Journal of Forecasting, Vol. 11, pp. 199–215.

After estimation, the predicted cash shares (S'_t) are found from $\exp(\alpha' + \beta' t) = (1 - S'_t) / S'_t$, where α' and β' are the estimated parameters while t now varies over the forecast period 2016–2026. Thus, similar to the approach used elsewhere by Khiaonarong and Humphrey,[10] $S'_t = 1/(\exp(\alpha' + \beta' t) + 1)$. The pattern of initial cash use is used (via symmetry around its inflection point) to predict the remaining pattern of replacement.

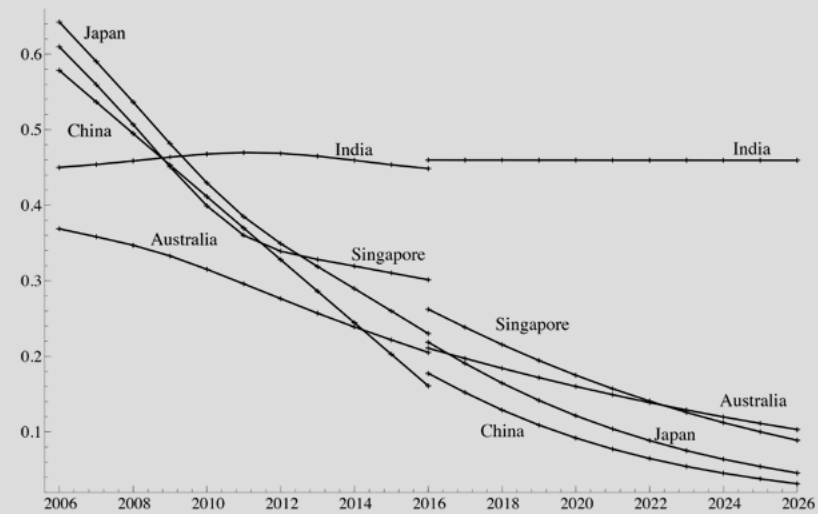
4.2. Forecast results

To forecast cash use, this paper uses only the CASHSHARE measure, where CASHSHARE = S_t or S'_t = (value of ATM + OTC cash withdrawals)/(value of ATM + OTC cash withdrawals + the values of card and e-money transactions). This is the preferred measure as it focuses on the market for cash purchases in a country and illustrates why it is falling via the expanded use of non-cash payment instruments in consumption. The results are shown in *Figures 3A* and *3B* (plot marks have been removed for clarity).

The observed cash shares over 2006–2016 are the same as shown in *Figures 2A* and *2B* and were fitted using a cubic spline. When estimated using data from the study period, however, the forecasting procedure imposes a reverse S-curve functional form. The results of this estimation were applied to the years 2016–2026 to obtain predicted values. This explains why there can be a break in the slope of the curves in 2016. The different slopes before and after 2016 reflect the fact that the measured cash shares prior to 2016 are not strongly compatible with the reverse Gompertz S-curve used in the forecast, indicating the degree to which this assumption differs from the data.

10 Khiaonarong, T. and Humphrey, D. (2005) 'Use and substitution of cash and electronic payments in Asia', South East Asian Central Banks Research and Training Center, Occasional Paper No. 42.

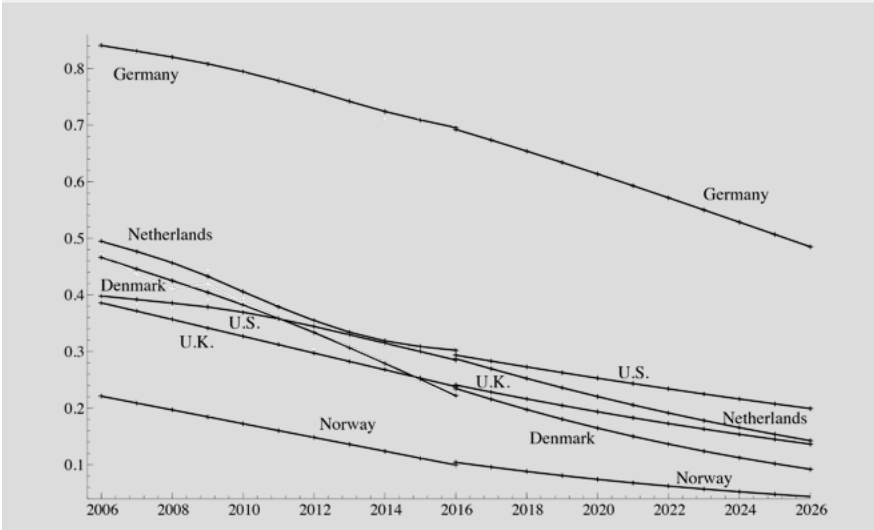
Forecast of Cash Shares, 2016-2026 Figure 3A



Were Equation 1 re-estimated using the observed (S_t) plus the forecasted (S'_t) cash shares, the curves would look connected and smooth over the entire 2006–2026 period. However, then there would be no indication of how closely the observed data matched the assumed functional form in Equation 1.

All cash shares, except for India, are forecast to fall between 2016 and 2026. The average reduction across countries over the ten-year forecast period is 13.5 pp, or 1.4 pp per year. As seen by comparing the cash use levels from 2016 to 2026 in *Table 2*, the largest reductions were for Germany (20 pp) followed by Japan and Singapore (17 pp each). The two smallest reductions were for India (0) and Norway (6 pp). Aside from Germany and India, which had the largest and smallest cash share reductions, respectively, most of the other countries do

Forecast of Cash Shares, 2016-2026 Figure 3B



not deviate far from the average cash share reduction of 1.4 pp a year. This is a little less than half the yearly rate of the CASHSHARE reduction observed over 2006–2016 (at 2.2 pp).

If accurate, this change would–as expected–be slower over time as Equation 1 specifies a reverse S-curve. That is, the reduction in the share of cash use should fall but at a slower rate as it approaches saturation (zero or minimal use). Note that were a ruler or simple linear equation used to forecast cash use, cash use would at some point become negative. Using a logistic curve avoids this impossible result.
In 2016, only Norway had a level of cash use of 10 per cent or less. By 2026, if the forecast is correct, Australia, China, Denmark, Singapore and Japan could join Norway in this 'low cash use' group.

Predicted Levels and Changes in Cash Shares for 2016 and 2026 Table 2

Country	Cash Level 2016	Cash Level 2026	Yearly Reduction pp
Australia	21	10	1.1
China	18	3	1.5
Denmark	24	9	1.5
Germany	69	49	2.0
India	46	46	0.0
Japan	22	5	1.7
Netherlands	29	14	1.5
Norway	10	4	0.6
Singapore	26	9	1.7
U.K.	24	14	1.0
U.S.	29	20	0.9
Average	**29**	**17**	**1.4**

Note: Numbers in the table have been rounded off.

5. The demand for central bank digital currency

An in-depth discussion of the merits of digital currency is beyond the scope of this paper, and in any case is available elsewhere.[11, 12, 13, 14, 15, 16] For the purpose of the present paper, it is sufficient to note that the two most important benefits of digital currency are: (1) a reduction in the cost of supplying cash to the public; and

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11 Ali, R., Barrdear, J., Clews, R. and Southgate, J. (2014) 'The economics of digital currencies', Bank of England Quarterly Bulletin, Q3, September, pp. 276–286.
12 Barrdear, J. and Kumhof, M. (2016) 'The macroeconomics of central bank issued digital currencies', Bank of England Staff Working Paper No. 605.
13 Danmarks Nationalbank (2017) 'Central bank digital currency in Denmark?, Working Paper No. 28.
14 Engert, W. and Fung, B. (2017) 'Central bank digital currency: motivations and implications', Staff Discussion Paper, No. 2017-16, Bank of Canada.
15 Mancini-Griffoli, T., Peria, M., Agur, I., Ari, A., Kiff, J., Popescu, A. and Rochon, C. (2018) 'Casting light on central bank digital currency', IMF Staff Discussion Note 18/08, International Monetary Fund.
16 Norges Bank (2018) 'Central Bank Digital Currencies', Norges Bank Papers, No. 1/2018, May.

(2) greater user convenience. Another benefit concerns access to a risk-free payment instrument. This could increase the demand for CBDC if banks are not trusted and/or adequate deposit insurance is not available.

Were digital cash to substitute for physical cash, the expense of printing currency, maintaining its fitness, building vaults and storage depots, and distributing cash would be markedly reduced (by way of illustration, the US Federal Reserve Board currency budget for 2018 was US$862m, which covered currency printing by the Bureau of Engraving and Printing, maintaining currency fitness, vault costs, protection, plus some transportation by Federal Reserve Banks, along with counterfeit deterrence). As the difference between these costs and the face value of currency represent seigniorage revenues, these revenues would be retained were digital cash to replace physical cash.

The greater convenience of digital cash depends on the method of access. Certainly, there is little improvement in convenience if a user has to travel to an ATM or bank branch on a weekly or twice weekly basis to reload a digital cash card or a mobile phone. However, were central banks to issue a digital cash card, POS terminals could be adjusted to accept it just like a bank debit card. Funds could be debited from a user's bank deposit account for each transaction.

Alternatively, like cashback at the POS, inserting a central bank card into a retailer's terminal could both pay for a transaction using bank deposit money as well as store cash on the card (up to a given level) for future purchases. Tokenised versions of having CBDC operate through banks are also being considered (in part to deal with the payment anonymity issue). Any of these arrangements would represent an improvement in convenience. Accessing digital cash would be less costly for banks than the expense they currently incur when providing physical cash. As a result, central banks could argue that the processing of these transactions should not incur bank fees; indeed, banks do not currently charge central banks for accepting, holding or disbursing currency.

A related issue facing central banks is whether the shift to digital cash would be sufficient to achieve other policy goals. Some argue that digital cash could provide a check on the market power of providers of cards and other substitutes for cash. Although access to cash through a bank deposit account could achieve this goal, it would not provide an alternative payment network in the event of a natural disaster or severe disruption to a privately-operated payment network, as was the case in June 2018, when the hardware failure experienced by Europe's VISA payment network resulted in an outage affecting cardholders across the region.

A way to achieve both goals would be to supply digital cash through user deposits at the central bank. These deposits would be accessed using a cash card, mobile phone or computer (via the internet). While this is more convenient than withdrawing cash today, its only improvement over bank-supplied payment instruments would be the presumed safety of its deposits as, unlike private banks, central banks cannot go out of business. Even so, the availability of an effective deposit insurance programme would remove this apparent advantage.

If users had a deposit at the central bank, processing digital cash transactions could be done independently from privately-operated processing centres. While this may sacrifice the scale benefits of processing digital cash transactions with (say) bank card transactions at a privately-operated processing centre, digital cash could operate as an independent and substitute payment network in the event of a national disaster or an operational disruption in the private sector. This is not the only way to insulate an economy from payment system disruptions. An alternative is already in place for large-value wire transfers in Europe (Target) and the USA (Fedwire) and could be applied to the processing of retail payments. This involves a duplicate processing centre processing the same transactions in real time as a backup, as well as alternative communication links and other disaster recovery procedures.

Accessing digital cash through a commercial bank or through a central bank clearly improves user convenience compared with withdrawing cash today. However, it merely makes digital cash equivalent to a debit card–not better. Increased convenience alone is unlikely to generate enough demand for digital cash to reduce the use of bank cards or other cash substitutes. It may not even be attractive enough to replace the value of cash currently being used in a country if the use of cash substitutes is already widespread and entrenched.

If CBDC is just as good as a bank debit card, why switch? This was one of the reasons why the reloadable cash card experiment in Europe did not gain sufficient traction.[17] Consumers saw little reason to have cash and a reloadable cash card in the same wallet. A similar argument can be made for digital cash when the existing population favours and relies strongly on cards and e-money. Thus, the demand for digital currency will be weak in countries where cash use is already very low.

Where cash use is currently high, because cash substitutes are not well developed or widely available, the improvement in convenience from CBDC by itself should generate a relatively strong demand. Offering CBDC here should have a response similar to that which occurred in countries where cash use is currently low because bank cards and e-money have replaced cash. It basically comes down to first-mover advantage. When introducing CBDC in a country with little use of cards and other cash substitutes, the fact that CBDC is as good as a bank debit card is an advantage. In countries where cards and e-money are already used extensively, something that is no better than a debit card offers no advantage.
This disadvantage could be addressed by setting a zero interchange fee for digital cash payments, putting digital cash on a par with physical cash. Further, by making the cost of accepting digital cash lower than that for accepting physical cash,

17 Van Hove, L. (2006) 'Why electronic purses should be promoted', Banking and Information Technology, No. 2, June, 20–31.

retailers would be financially motivated to adopt digital cash. The combination of a zero interchange fee for digital cash payments and a sufficiently lower cost to accept digital cash relative to physical cash would undoubtedly encourage retailers to find a way to induce customers to use digital cash instead of a bank debit card. For example, the retailer could waive a fee or offer a reward when the customer uses a central bank digital cash card, while charging a fee or providing no reward when the customer uses a bank card. Added to the increased convenience of digital cash, how it is priced to retailers, and their response, will be important in determining the demand for digital cash by potential users (and its viability over time). In addition, as CBDC could in this situation be favoured over private bank cards, having the central bank compete with the private sector may raise some concern as tax revenues would be making this possible.

6. Summary and conclusions

To date, the discussion regarding digital cash has chiefly centred on supply-side concerns–the benefits of digital cash, why it may be needed, how it could be structured, and the possible effects on monetary policy or financial stability if implemented. If implemented, however, the success of digital cash would depend on the demand for it. The demand for digital currency largely depends on a country's current level of cash use and how rapidly it may be falling. In turn, this is determined by the cost and convenience of CBDC for potential users relative to payment instruments that have already replaced many cash transactions in some countries, showing the preference for cash substitutes over physical cash.

This paper has identified four measures of cash use. In one, cash use is generally rising; for the other three, however, it is almost always falling. For the reasons noted in the text, this paper has used one of the latter three measures as its preferred measure. This measure represents the market for cash and shows why cash use is falling (ie because cards and electronic money are replacing cash payments). The other measures do not do this and are less informative.

Using this measure, the average reduction in cash use for the period 2006–2016 was 2.2 pp per year. Relative to the average level of cash use over this period (39 per cent), the average yearly reduction was 6 per cent. In countries where the level of cash use is already very low, due to a strong realised preference for cards and mobile phone payments, demand for CBDC will be weak. This will limit the ability of CBDC to compete for market share when the market is dominated by bank cards, electronic money and mobile phone payments. A market share of 10 per cent or less, like that in Norway, likely applies to other countries not in the sample. Furthermore, based on this study's forecast for future cash use, Australia, China, Denmark, Singapore and Japan will have joined Norway in that 'low cash use' group by 2026, with similar implications for CBDC demand.

Although convenience is improved relative to obtaining physical cash from an ATM, without additional incentives CBDC will only be as good as a bank debit card–not better. Where CBDC is no better than existing substitutes in the market for cash payments, low demand will inhibit its adoption, regardless of how it is supplied. In countries where the use of cash substitutes is neither widespread nor well established, the currently high level of cash use means they can wait a while and observe the effects of CBDC if and when others implement it. Furthermore, if they do decide to implement CBDC, the demand should be relatively strong as, even though it is only as good as a bank debit card, there are few cards or other cash substitutes to compete with.

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The Future of Cash in a Digitized Economy

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Abstract

It is widely assumed that cash will no longer play any role in a digitized economy, except probably for criminal activities and tax fraud. However, the first question is: When is an economy digitized? Secondly, what are the technical, legal and economic preconditions for a complete elimination of cash? Thirdly, is the reappearance of cash conceivable once it is gone? Applying the so-called Kranzberg-completeness of new techniques and Polanyi's "tacit dimension of knowledge" concerning the application of new techniques, in combination with economic theory, the above questions are analyzed. According to Kranzberg, new techniques–for instance, smartphone payment methods–require not only the electronic techniques, but also a number of additional inventions, i.e. technical inventions (e.g. for cyber security), institutional inventions (e.g. standardizations), and legal inventions (e.g. liability rules). In the sense of Kranzberg completeness, most new techniques are incomplete. An economy is digitized if the digitization is Kranzberg-complete. This gives the first answer to the second question: cash as a means of payment and as a store

of value requires that the digitized media replacing it must be Kranzberg-complete. In addition, customers must accept these new media. According to Polanyi's "tacit dimension of knowledge", people are using cash mindlessly, so to speak, but this requires tacitly available knowledge. This is the second part of the answer to the first and second question: An economy is digitized and cash will vanish if the digitization of the economy and of money is Kranzberg-complete and Polanyi-secure (i.e., tacit knowledge to use the new media is available). However, under certain conditions the reappearance of cash might be possible.

1. Introduction

As even the economists of the IMF asserted recently, cash is still king (Agarwal and Krogstrup, 2019). Nevertheless, cash is under political pressure for a number of reasons (see, for instance, Rogoff, 2014):

(a) Cash supports the so-called shadow economy since cash payments are anonymous and cannot be tracked. Moreover, it fosters tax evasion for the same reasons.
(b) Cash is very often involved in other criminal activities, as most obviously in bank robberies, but also in blackmailing, corruption and even terrorism.
(c) Cash makes it difficult or even impossible to enforce negative interest rates (Assenmacher and Krogstrup, 2018; Agarwal and Krogstrup, 2019).

As it seems, cash is involved in, if not among the major sources of, several serious societal issues and macroeconomic difficulties. However, as demonstrated by Schneider (2017) and Seitz et al. (2018), cash has only a very restricted relevance for the above-mentioned crimes, but is highly relevant for civil liberties.

In this paper, the objective and contribution to the literature is to analyze the conditions for a cash-free, fully digitized monetary economy. In such an economy, cash in form of bank notes and coins would no longer exist, at least officially and legally. Money and currency would only be digital codes in devices like smartphones, computers etc. Although it is yet possible today to transfer money by mobile electronic devices, cash is still king. This leads to the question why cash has not been replaced already by digital money or why the latter does not dominate as a method of payment.

The answers to these questions are not simple ones. It is known from other technical innovations that it takes a lot of time until innovations are accepted and employed. At first glance, it might seem as if people react negatively to all kinds of novel products and devices for psychological reasons. This impression is not completely correct. In this paper, the so-called Kranzberg completeness concept (Kranzberg, 1986) for new techniques and Polanyi's idea of the tacit dimension of knowledge (Polanyi, 1966) are applied to explain why the adoption of new devices is delayed and how the adoption might be accelerated, if required. The main content of Kranzberg completeness is the question when an innovation is really ready for adoption, i.e., when the innovation is complete. As explained by Kranzberg, a technique might be incomplete technologically, institutionally and legally. That is, new techniques lack very often additional inventions and innovations to become applicable on a large scale. Put differently, a device that works in a lab or in small-scale applications, will not necessarily work under real-life, large-scale conditions. To recognize such issues in the context of payments, a comparison of required and actual available characteristics of cash on the one hand and electronic payments on the other hand is important.

The same holds true for Polanyi's tacit dimension of knowledge. This means that people know much more than they themselves realize when they are acting in their economic, technical and social environment. That is, they follow certain so-called scripts they learned before, mostly on a trial-and-error basis. With new and probably disruptive techniques that are quite different from the methods they used to apply, such scripts are not available. It is then the lacking tacit knowledge that delays (or even inhibits) the application of new techniques. This holds also seemingly true for electronic payment devices in comparison to cash, bank cards and credit cards.

Together, Kranzberg incompleteness in combination with a lack of Polanyi-knowledge may suffice to delay or even to prevent the diffusion of new devices as, for instance, digital payment methods.

The remaining of this paper is structured as follows. In Section 2, the digitization of an economy is studied concerning the questions what digitization means and when it is completed. Of course, the particular focus is here on payment methods. The main characteristics of cash payments, as seen from the users' perspective, are the topic of Section 3. These characteristics are compared in Section 4 with the characteristics of digitized payments, as they are available now. In Section 5 it is asked whether and under which circumstances cash will vanish completely from the legal circulation of money. Moreover, it is asked whether or not cash payments may reappear after their disappearance. Section 6 concludes.

2. Digitization: What is it, when is it completed?

Mervin Kranzberg analyzed the history of technology from the viewpoint of a historian (Kranzberg, 1986, pp. 544 f.). He formulated the essence of this study in six "laws", whereof four are relevant for this paper[1]:

1. "Technology is neither good nor bad; nor is it neutral" (Kranzberg, 1986, p. 545). Technology interacts with its societal environment and it is implemented in a certain historical situation in such a way that the intended purposes of the technology may frequently deviate largely from its real consequences. Moreover, the consequences of new techniques can be quite different, depending on the society in which they are introduced.

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1 The fifth "law" reads: "All history is relevant, but the history of technology is the most relevant" (Kranzberg, 1986, p. 553) and the sixth "law" is: "Technology is a very human activity–and so is the history of technology" (Kranzberg, 1986, p. 557).

2. “Invention is the mother of necessity” (Kranzberg, 1986, p. 548). This is one of the crucial aspects of new technical devices that are stressed in this paper. It puts upside down the saying “necessity is the mother of invention”. However, the implication of Kranzberg’s second “law” is that to make inventions effective, further inventions and innovations are required. Put differently, an invention is not the endpoint of a development, but a starting point for a series of necessary complementary inventions.
3. “Technology comes in packages, big and small” (Kranzberg, 1986, p. 549). In a sense, this is an extension of Kranzberg’s second “law”. Only when the package of a new technical development is finalized, it reaches a degree of completeness.
4. “Although technology might be a prime element in many public issues, nontechnical factors take precedence in technology-policy decisions” (Kranzberg, 1986, p. 550). Decisions to adopt new techniques are more or less political decisions, rather than technical ones. If the relevant infrastructure, institutions and legal frameworks do not fit the new techniques, they will not, or not effectively and efficiently, be adopted.

All in all, it can be said that the first “Kranzberg law” is a general statement that technology inventions and innovations are embedded in a historical and societal context that must be considered when new techniques become available. Therefore, as stated in the fourth “law”, the effective and efficient introduction and application of new technical devices requires institutional and legal framework innovations. If these frameworks are established, the lacking technical inventions can be made. The reason for the latter is that only after this framework is created, the technical lacks and gaps become visible to their full extent. In this way, the small or big technology package emerges finally.

In a certain sense, a new “technology package” in the sense of Kranzberg’s third “law” may be a so-called “disruptive technology”. As defined by the Fraunhofer-

Institute for Production Technology: "Disruptive technologies are innovations that replace the success of an existing technology, of a product or a service or that drive them completely out of the market" (Fraunhofer-Institut für Produktionstechnologie, 2019, Homepage; own translation from the German original[2]).

The digital economy is defined by the use of computers and information technologies that are based on digital computing devices where business is carried out over the internet and the network of the World Wide Web (Wikipedia, 2019a, Digital Economy). A better description and measurement are possible via DESI (Digital Economy and Society Index) of the European Commission, introduced in 2014 (see also the biennial OECD Digital Economy Outlook, OECD, 2017). The index encompasses five areas (EU Commission, 2018, p. 1):

1. Connectivity (broadband equipment of the economy and its prices)
2. Human capital (skills and internet use)
3. Use of internet service (citizens' internet use for all kind of activities and transactions)
4. Integration of digital technology (digitization of business and e-commerce)
5. Digital public services (eGovernment and eHealth)

According to DESI 2018, Denmark, Sweden, Finland and the Netherlands are the most advanced digitized economies whereas Germany is in the middle of the EU-28 countries, just slightly above the EU mean value. However, according to this index, the most advanced digitized countries reach about 70 of 100 points. Concerning the "integration of digital technology" in business activities, Germany gains just over 40 of 100 points.

2 „Disruptive Technologien sind Innovationen, die die Erfolgsserie einer bereits bestehenden Technologie, eines bestehenden Produkts oder einer bestehenden Dienstleistung ersetzen oder diese vollständig vom Markt verdrängen."

For the economy as a whole, one can say that the digitization is far from completion. This holds true for Germany and even for the most advanced digitized countries (i.e. for Korea and the Top-4 European countries).

In *Table 1*, a possible Kranzberg matrix for the digital economy as a whole is developed. The Kranzberg completeness conditions (KCC) are indicated in the first row of the matrix. The first column contains the (supposed) characteristics a fully digitized economy should guarantee. It is not intended here to put values into the Kranzberg (in)completeness matrix. The purpose of *Table 1* is to demonstrate how the Kranzberg completeness of a technology can be determined. The KCC are, therefore, the most important part of the table.

The KCCs read as follows.

(a) Digital technology means the complete technical package that is required for the digital economy.
(b) Technical infrastructure denotes the technical preconditions for providing any kind of digital data and its transmission. For instance, continuous availability of electrical power is one of these conditions, as are the glass fiber backbones of the internet and the connections of these backbones to homes and enterprises.
(c) Social institutions are also a precondition of the digital economy as they are those moderating forces that are required to deescalate conflicts that may accompany disruptive technologies.
(d) The legal framework is to be adjusted in such a way that digital transactions can be carried out on a secure basis. One of the most important ingredients of the legal framework are liability rules.

A Kranzberg (in)completeness matrix for the digital economy — Table 1

	Digital technology	Technical infrastructure	Social institutions	Legal framework
Usability				
Security				
Access				
Compatibility				
Ubiquity				

The five supposed characteristics of a digital economy are:

(a) Usability: All features of economic transactions are easily conducted digitally.

(b) Security: all transactions are secure (for instance, cannot be hacked) and a high level of privacy is guaranteed; identity theft is very difficult if not impossible.

(c) Access: The internet, the World Wide Web can be accessed everywhere. Nobody is excluded from internet access.

(d) Compatibility: All economic transaction systems are compatible with each other.

(e) Ubiquity: There is no media disruption. This means that all economic transaction can be carried out within the digital world. This must also hold for transactions with authorities as, for instance, fiscal authorities (taxation) (eGovernment, eHealth etc.).

In a completely digitized economy, all economic transactions involving payments will also be executed electronically. Insofar, electronic money will be an essential and indispensable feature of a digitized economy. However, it is not clear what characteristics such a payment method and its background payment system should guarantee.

To find this out, the main characteristics of the cash payment method are determined firstly from the users' viewpoint and secondly from a systemic aspect (Section 3). Having done this, the characteristics of electronic payments can be specified (Section 4).

3. Cash characteristics

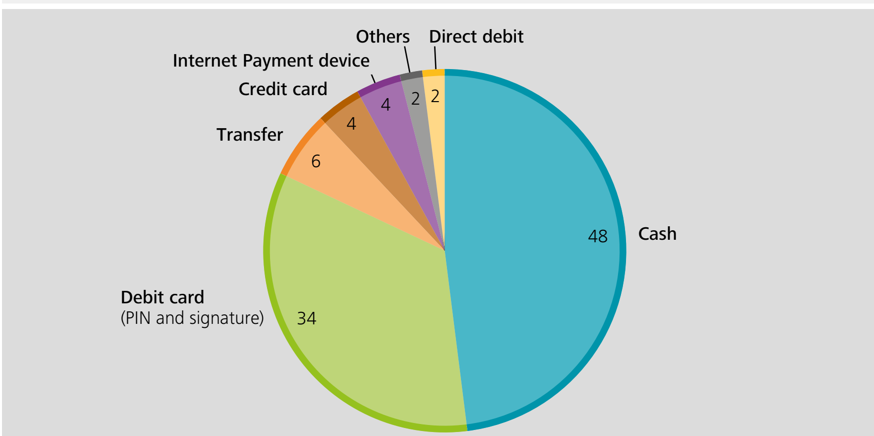
3.1 The users' view

According to § 3 Bundesbank Act, as interpreted by the Deutsche Bundesbank (Thiele, 2017, p. 3), the citizens decide whether they pay cash or otherwise. Therefore, the analysis of the existing preferences concerning payments reveals the payment characteristics citizens in Germany value the most.

Figure 1 shows the relative shares of payment methods in Germany 2017. Accordingly, a bit less than half of all payments with respect to sales values were

Used payment methods, Germany 2017 Figure 1

in % of sales value



Source: Thiele (2017), p. 7 (here rounded to full percentages).

paid by cash. Although the value in 2017 (47.6%) is about ten percentage points lower than in 2008 (57.9%; Deutsche Bundesbank, 2017, p. 24), the share of cash payments is still high. Meanwhile the use of debit cards increased from 25.5% to 34% (Deutsche Bundesbank, 2017, p. 24). Internet based payment methods had a share of 3.7% in 2017 (0.3% in 2008; Deutsche Bundesbank, 2017, p. 24) and mobile payments still play no role at all.

The relevance of characteristics is shown in *Table 2*.

Relevance of payment methods' characteristics and their degree of performance by method (answers in % of all respondents) Table 2

Characteristic	**Indispensable**	**Rather important**	**Cash** performance	**Debit card** performance	**Internet payment** performance
Security against financial loss	75	24	44	48	13
Oversight into spending	69	30	91	52	11
Simple use	59	38	94	71	20
Familiarity	56	39	96	72	17
Privacy protection	66	28	93	30	5
Quick payment procedure	34	52	89	66	21
Broad possible use	39	43	80	74	15
Financial benefits	7	24	39	25	13

Source: Own compilation and translation of Deutsche Bundesbank (2017), Abb. 7, p. 24.

The results represented in *Table 2* are essential for the relevant payment characteristics from the users' viewpoint. With the exception of "security against financial loss", cash payments perform best in all other categories according to the answers of the respondents of the Bundesbank's interviews. In all respects, internet payments lack far behind. Furthermore, as indicated by *Table 2*, more than half of the respondents say that the following characteristics of payment methods are indispensable:

1. Security against financial loss,
2. Oversight into spending,
3. Privacy protection,
4. Simple use and
5. Familiarity.

Note that these are the most relevant criteria for payment methods from the users' viewpoint. They are not necessarily conforming to the above characteristics of a digitized economy (usability, security access, compatibility and ubiquity) since the above criteria are systemic (and not individualistic) ones. Nevertheless, for users of payment methods the individual characteristics are decisive for the adoption of the methods.

3.2 Polanyi's "tacit dimension" and Kranzberg-completeness

The first three characteristics from the users' point of view can be understood from simple microeconomics. Security and spending oversight are due to the payment method users' budget constraint. Security against financial losses is necessary to protect the own budget. The oversight requirement indicates that the users take account of their budget restrictions when spending money. Privacy protection is a means to hide the own preferences from the unauthorized eyes of other people and from the data-hungry agency that sell these data to the producers of goods and services. Privacy protection means in this interpretation that the customers attempt to protect their consumer surplus.

The characteristics four and five above can also be understood from microeconomics, as simplicity of and familiarity with the use of a payment method reduces the time needed to complete the payment securely and it decreases the potential errors. Moreover, these characteristics indicate also the importance of the "tacit dimension of knowledge" that Michael Polanyi emphasized (Polanyi, 1966; see Cowan et al., 2000, for a critical discussion of tacit knowledge and its application in economics). Simplicity of use and familiarity are one and the same thing in this respect. Because people know tacitly a lot about using cash and something about the use of debit cards, they do not have much or even any tacit knowledge concerning the use of internet payments and mobile payments. As a consequence, they do not have a so-called "script" according to which they may routinely pay with the latter methods.

According to Lam (2000), four types of knowledge can be distinguished. From the viewpoint of the individual, it is explicit and tacit knowledge. Explicit knowledge encompasses theoretical and conceptual skills, as well as cognitive abilities (Lam, 2000, p. 492). In contrast, tacit knowledge is action-oriented and practical. As Lam put it (2000, p. 491 f.), tacit knowledge is "embodied", whereas explicit individual knowledge is "embrained".

On the collective level, explicit knowledge exists as information, signs and symbols; moreover, it can be codified (Lam, 2000, p. 491 f.). As collective tacit knowledge, it shows up as routines and shared norms. Lam dubs explicit collective knowledge "encoded knowledge" and the tacit version "embedded knowledge" (Lam, 2000, p. 491 f.).

In the context of this paper, the individual and collective tacit knowledge are of great interest. Both knowledge versions are lacking with respect to digital money and digital payment methods (except debit and credit cards). The consequence is that the use of these payment methods and monies

1. take much more time,
2. are error prone and
3. cause uneasiness.

All these effects are economically relevant. Time has an economic value as it has alternative usages; hence, the more time it takes to complete a payment, the higher the opportunity cost of it. Errors are costly since it costs time to correct them and it may also cost money. Uneasiness is a negative feeling that is economically relevant as people would like to spend some money to get rid of it.

For these reasons the lack of "(individual and collective) tacit dimension knowledge" with digital payment methods is not only psychological important, but also an economic obstacle to the adoption of those payment methods.

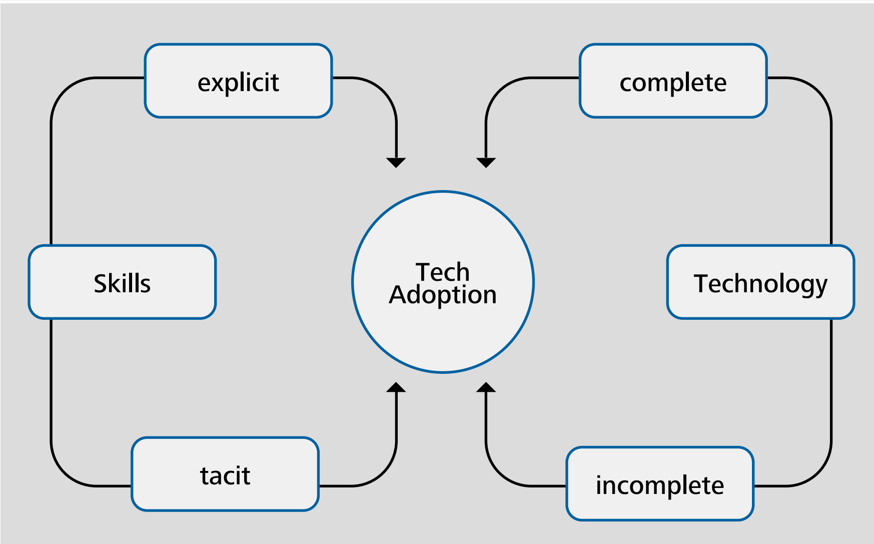
Figure 2 summarizes the dimensions of tech adoption in a Kranzberg-Polanyi framework. The Kranzberg aspects are systemic whereas the Polanyi characteristics are individualistic and societal. On the individual side, skills that are required for the adoption of new technical devices are explicit insofar as the application must be understood. However, there is also a Polanyi-tacit version of skills required that make the application quick, easy and secure. Those skills are neither obvious nor are they explained in operation manuals. They must be acquired by using the devices and by imitating the behavior of other persons. On the societal side, routines are missing too. Kranzberg-completeness would make it much easier to learn the required tacit skills to apply the new device and it would allow to apply the respective routines.

From the side of the technology, the package of devices may be either complete or incomplete. Very innovative and disruptive technologies are, as argued above, Kranzberg-incomplete at the beginning. Hence, the incompleteness of technical innovation, in combination with the tacit dimension of skills for using them, makes adoption difficult, time-consuming and rather lengthy.

The combination of the systemic Kranzberg technology (in)completeness and the Polanyi tacit dimension of knowledge explains quite well the dominance of cash

Tech adoption, technology and skills in a Kranzberg-Polanyi framework

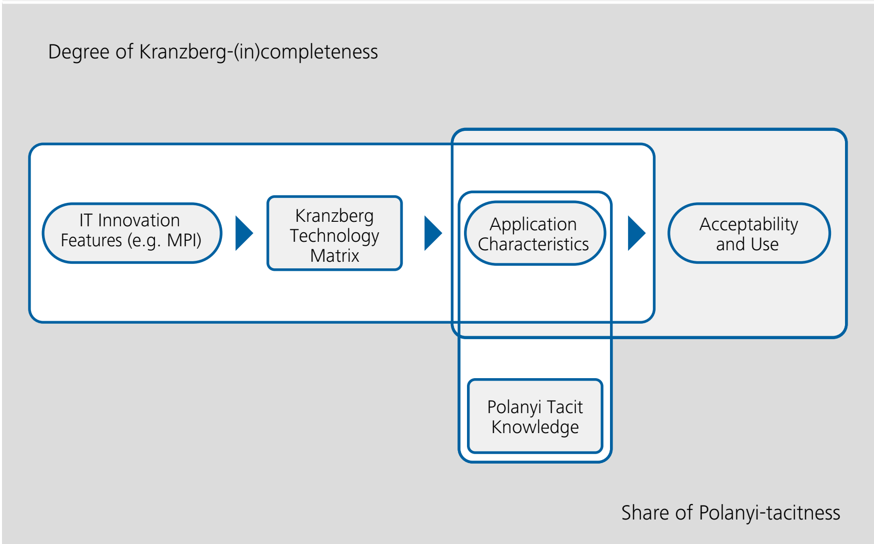
Figure 2



Source: Own depiction

payments in Germany (and why cash is still king worldwide): Cash as a payment method is very well known since more than 100 years. Technologically sophisticated, institutionally very well secured and with a very clear and well-known legal framework, cash is a Kranzberg complete technology. Additionally, since it is in use for such a long time, the individual and collective tacit knowledge is also sophisticated. There are scripts and routines on how to behave in everyday situations that involve cash payments. Similar is the situation with debit card payments. However, although the Kranzberg completeness of this technology seems to be comparable with that of cash payments, the tacit knowledge concerning this method is less developed. The latter aspect emphasizes the importance of the tacit knowledge dimension. *Figure 3* summarizes these aspects in a diagram.

Technology acceptability and use in a Kranzberg-Polanyi framework Figure 3



Source: Own depiction
Note: MPI: mobile payment instruments

As indicated in *Figure 3*, Kranzberg-(In)completeness and tacit knowledge interact with each other. To demonstrate this in greater detail, *Table 3* combines different degrees of Kranzberg-(In)completeness (K-(in)complete) and the explicit, as well as tacit, knowledge of skills to predict the technology's adoption.

According to the (tentative) predictions on tech adoption, the most successful tech adoptions occur with K-complete technologies, even if they require tacit knowledge. Moreover, the adoption process will very probably be smooth, without disruptions. This is very different with K-incomplete technologies. If they require no or new explicit skills only, their adoption may become highly disruptive and slow. If the precondition for the technologies' application are elaborated tacit skills, they will not be adopted. Partially K-incomplete technologies are in-between K-complete and K-incomplete technologies. The adoption process becomes more disruptive and slower than with K-complete technologies.

Tech adoption, degrees of Kranzberg-(In)completeness and skills Table 3

	Tech is K-complete	Tech is partially K-complete	Tech is K-incomplete
Tech requires no new skills	Smooth tech adoption	Some degree of tech disruption/ delay	Highy disruptive tech adoption
Tech requires new explicit skills	Smooth tech adoption with training	Disruption and/ or delay despite of training	Highly disruptive/ highly delayed adoption
Tech requires new tacit skills	Smooth tech adoption with learning-by-doing	Slow tech adoption with disruption	No adoption
Tech requires new explicit and tacit skills	Smooth, but slow tech adoption	No or very slow tech adoption	No tech adoption whatsoever

Source: Own depiction

4. Characteristics and adoption of digitized money

As said by the philosopher John R. Searle, money is a “status function”: “The status function is a function that is performed not in virtue of the physical features of the object or person in question that has the status function, but in virtue of the fact that there is a collective acceptance that the object or person has a certain status and a function that can be performed only in virtue of the collective acceptance of that status” (Searle, 2017, p. 1459). Moreover: “… [M]oney is like various other types of status function in that something is money only if everybody believes that it is money and that everybody believes that everybody else believes that it is money and everybody believes that everybody else believes that everybody else believes that it is money and so on. Some money is believed to be money in virtue of some other feature" (Searle, 2017, p. 1461).[3]

Why are these philosophical views relevant for economics and, perhaps, monetary policy? The main reason is that economic subjects act not only on incentives, but also on beliefs. For instance, as known by psychologists, people systematically overestimate the size of small risks and they underestimate the size of large everyday risks. As a consequence, a large majority does not wear helmets when biking, but fears the radiation of cell phones. In this paper, it is conjectured that such phenomena are related to Polanyi's tacit knowledge. When biking, most people implicitly know and anticipate the risks and adjust to them. In contrast, the risks of cell phones are neither visible nor did people have the opportunity to develop the required tacit knowledge up to recently. The wide adoption of cell phones demonstrates that the tacit knowledge is developing and the radiation fears decline.

Applied to IT and digital forms of money, the theoretical and empirical work on tech adoption is relevant (see Lai, 2017, for a recent literature review). In this respect, the findings of Venkatesh et al. (2003; 2012; see also Prinz, 2019) say that the following factors are in general the driving forces of adoption:

(a) performance expectancy,
(b) effort expectancy,
(c) social influence,
(d) facilitating conditions,
(e) hedonic motivation,
(f) price value and
(g) habit.

3 The view of Searle was criticized among others by Smit et al. (2011) who stress that money can also be explained by actions and incentives. Tieffenbach (2010) juxtaposed Searle's collective theory of money with the individualistic theory of Menger. Papadopoulos (2015) defended Searle's collective intentionality approach that seems to support the so-called state theory of money.

In addition,

(h) age,

(i) gender and

(j) experience

play also a role.

Venkatesh et al. (2003; 2012) emphasize that habit and experience play a crucial role because they have a direct impact on behavior. The latter stresses again the particular importance of the tacit knowledge aspect with new technologies. Lacking experiences implies lacks of tacit knowledge; existing habits–as embodied knowledge, as it were–increase the opportunity costs of adopting new technologies. Hence, not only the uncertainty concerning the new technology but also the increased opportunity costs delay the adoption of new technologies. However, the above general adoption-determinants of Venkatesh et al. may be interpreted as a combination of factors that are summarized in *Figure 2* as systemic Kranzberg-technology factors and individualistic Polanyi-skill factors.

Table 4 contains a very preliminary and only tentative evaluation of the Kranzberg-incompleteness of existing payment methods for Germany in particular. According to *Table 4*, almost all Kranzberg-completeness criteria are missed. As it seems, the technical infrastructure, but also social (supporting) institutions and an adequate legal framework are still principal obstacles to an adequate payment system for a digitized economy. For instance, Germany ranks 31th concerning the speed of fixed broadband internet access whereas it ranks 45th in mobile access (IT-daily, 2019). According to Nier (2018), Germany is the poorest performing European country concerning the speed of mobile internet access and an LTE-network coverage of 65.7% only.

As demonstrated in Section 3 above, internet payments play a marginal role in Germany; moreover, mobile payments are almost negligible. The reason is given

Table 4

Kranzberg-incompleteness of the existing payment methods for the digital economy

	Digital technology	Technical infrastructure	Social institutions	Legal framework
Usability	Many transactions cannot be carried out digitally	The technical digitized payment infra-structure is incomplete	Consumer protection is usually strong, but not for all transactions	Not all transaction can legally be carried out online
Security	Most digital payment methods are insecure	Cyber-crimes with credit cards etc. are wide-spread	Not well developed for internet payments	Liability rules for digitized payments are complicated or not specified
Access	Internet access is not guaranteed every-where	The German internet access is slow	Difficult and rather expensive	Difficult and expensive to get reliable legal information on payment method liability rules
Compatibility	Available digital payment methods are incompat-ible	Infrastructure is full of holes	Not applicable	Payment methods are le-gally not created equally
Ubiquity	Payment media disrup-tion is the standard	Internet is neither every-where nor all the time available	Not applicable	Legal rules on payment methods differ widely or are not specified

Source: Own depiction

in *Table 4*: these kinds of money do not match the characteristics economic subjects are looking for. Of course, as just explained, the lack of experience and tacit knowledge for using digital money (in particular represented by mobile payment methods) is one of the key factors for this. Nevertheless, it is also a clear indication for Kranzberg incompleteness of digital money. The latter is emphasized by a study concerning the acceptance of mobile payments in Germany (Beutin and Schadbach, 2017). The most relevant critical aspects of mobile payments are (Beutin and Schadbach, 2017, Fig. 7, p. 12):

(a) "Security and data protection",
(b) "Lower fees than other payment methods" and "Easy and fast use",
(c) "Widespread offering and acceptance",
(d) "Fewer obstacles like PINs or passwords", as well as
(e) "App with attractive products or services" and "Usage by family, friends and colleagues".

To sum up, the lack of acceptance of digital payment methods in Germany (and also in other developed countries; see Prinz, 2019, for a review of the relevant literature) can be categorized as follows:

1. The technology of digital money is Kranzberg incomplete in all respects (see *Table 4*):
   (a) The technology itself is incomplete since it cannot guarantee security and data protection as cash (and debit card) payments.
   (b) The technical infrastructure is in its infancy since there is even no internet connectivity in some parts of Germany, mobile payment methods are not widely available and the available forms are neither compatible with each other nor interconnected.
   (c) The relevant social institutions that support economic subjects in applying digital money and in conflict resolution are also in their infancy.

(d) The legal framework is complicated and, in some respect, not existent. In particular, the liability rules are adjusted to the use of cash and card payments, but not to digital money, whatever its form.

2. Economic subjects lack the tacit knowledge that is required to apply digital money quasi automatically in everyday transactions. Moreover, since the technology itself is Kranzberg incomplete, people do not have the opportunity to acquire tacit knowledge via learning-by-doing.
3. Due to network externalities, the providers of digital money develop proprietary payment solutions that are not compatible with each other. Although competition between digital payment systems is in general economically reasonable to find the best solution, the existence of large network externalities may contradict this. As it seems, either standardization or mandatory interconnectivity might be necessary to solve this issue.

The most recent development in the area of digital money is the so-called blockchain technology (Burgwinkel, 2016). As demonstrated by so-called Fintechs, the entire financial industry is on the verge of digitization (KPMG, 2015; Alt and Puschmann, 2016). Several exclusively digital monies, also called cyber money, virtual money or cryptocurrency (see, for instance, Vigna and Casey, 2015), have been developed and implemented, with Bitcoin as the best known case in point. Even the IMF discussed virtual currencies (He et al., 2016).

The issues 1. to 3. mentioned above can very clearly exemplified with these monies. First of all, these monies are private monies since they are not issued or backed by states. They are competing with each other and there is no standardization. Acceptance is voluntary. Hence, network externalities are very high with the consequence that most of these digital monies are not generally known or used; they are also called "nerdy money" (Kaplanov, 2012), for obvious reasons. As is well known, such network externalities imply inefficient markets for (private) monies (Prinz, 1999; Gans and Halaburda, 2015). Although Bitcoin (Böhme et al., 2015) has emerged as the most important cryptocurrency, it is not yet known whether Bitcoin is really money or just a speculative type of investment (Baek and Elbeck, 2015).

Even the private digital monies are Kranzberg incomplete in all respects. As the Bitcoin debacle demonstrated, Bitcoins can vanish from collection centers (the Mt. Gox case) without a trace, and fraud is possible. Although the blockchain technology seems to offer a basis for secure transactions, all kinds of digital systems can be hacked. Beside the network externality, the lack of a legal framework is an additional incompleteness issue. Moreover, even experienced computer users may lose money in a digital system that they do not fully understand and where they do not have the necessary tacit knowledge.

A completely digitized economy, as it seems, requires digitized money, too. The main reason is to avoid media disruptions. If this diagnosis is correct, it would be reasonable that central banks provide digital money. Assume that this will occur sometime in the future. What would be the consequences of the disappearance of cash?

5. The disappearance of cash … and its (possible) reappearance

Probably the most important economic question is whether it is efficient to have more than one payment method and store of value.[4] At first glance, the answer seems clear: because of network externalities, one method might be sufficient for economic efficiency. However, as documented above, from the users' point of view there are five characteristics money must provide: (1) security against financial loss, (2) oversight into spending, (3) privacy protection, (4) simple use and (5)

4 It is not intended to discuss the macroeconomic effects of the so-called „de-cashing" of economies; see Kireyev (2017) for such an analysis.

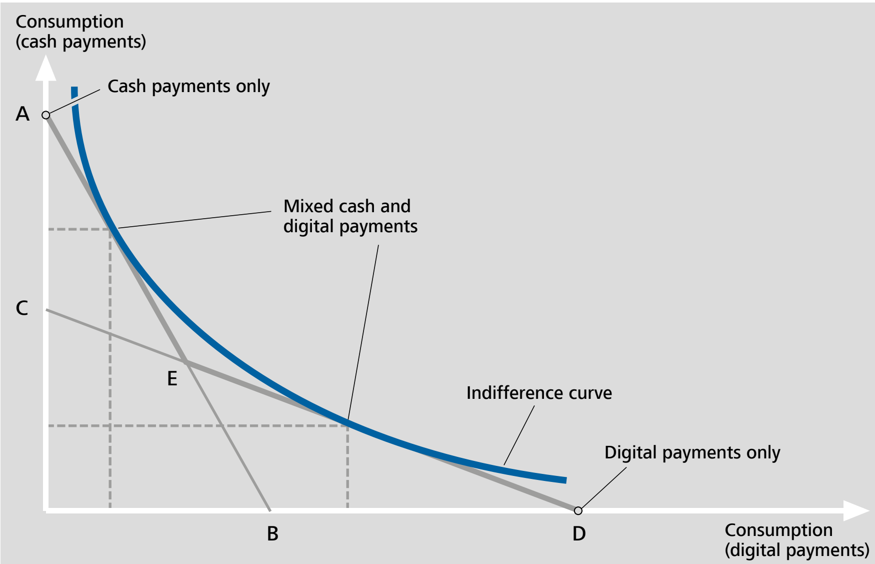
familiarity. As shown in Prinz (1999), it is possible, and even likely, that there is no dominant method of payment. Dominance means that a payment method fulfils all five criteria for all purposes better than the alternatives. Without a dominant payment method, a (probably small) number of methods will coexist. If this is the case, the payment methods are complements to each other. This is also the result of a study on currency demand in Japan (Fujiki and Tanaka, 2010). According to this study, households do not reduce cash holdings when electronic money is available and used. Put differently, the purposes and the methods of payments must be matched.

Nonetheless, payment methods may also be substitutes for each other. To see this, imagine that payment methods involve costs, for customers as well as for merchants (see Krüger and Seitz, 2014, for an overview of the costs of different payment methods in Germany and other countries). Although these costs are not very visible–in particular with cash payments–they exist. With different costs of payment methods, they become substitutes for each other for a given purpose. As long as there is no dominant method, i.e., a method that is not only superior with respect to the desired characteristics of the method, but also concerning the cost of providing the characteristics, several methods will remain. In other words, there will be competition between the methods.

In *Figure 4*, the decision between cash and digital payments (*payment methods*) for consumption expenditures (*given purpose*) is diagrammatically described. The lines AB and CD, respectively, represent the budget constraints that are relevant for both payment methods (the lines intersect at point E). The different slopes of the lines represent the relative costs (monetary and non-monetary) that are involved with the use of the respective payment methods. In addition, an indifference curve for these payment methods is depicted, too. The indifference curve depicts the utility level of customers for the combination of the respective payment methods. This curve represents the utility effects of the different characteristics of the

Payments for consumption expenditures: cash versus digital money

Figure 4



Source: Own depiction.

payment methods. For instance, cash payments are made anonymously whereas digital payments are observable and stored. As a result, depending on the relevant budget line, a mix of cash and digital payments emerges as a payment pattern. As depicted in *Figure 4*, cash and digital payments can be substitutes to each other.

The corner points for cash-only and digital-only payments are also shown in *Figure 4*; these are the points A and D, respectively. However, these points will not be chosen voluntarily as long as the characteristics of the payment methods differ from the customers' perspective. If digital payments were made mandatory by law, the welfare level of customers would decline (point D, as well as point A) are located below the indifference curve; this implies lower welfare levels). From *Figure 4*, it is not so surprising that a protest movement is forming "pro cash" in Sweden (Arvidsson, 2019, pp. 66 ff.). The reason is that Sweden is the European country that relies the least on cash and finds itself on the route to a "cashless society" (Arvidsson, 2019).

From *Figure 4* and the reasoning above it can be concluded that the following conditions must be fulfilled for the disappearance of cash, even if the respective payment method technologies are Kranzberg-complete:

1. Digital payment device(s) must exist that is (are) superior to cash concerning security against financial loss, oversight into spending, privacy protection, simple use and familiarity.
2. The cost of digital payment devices must be lower in respect to all desired characteristics than cash payments.

At the time being, it is far from clear whether digital payment methods will ever be superior to cash in all five individualistic characteristics. For instance, to guarantee equally security and simple use with digitized money will be very difficult. Online banking (with and without TANs) is a case in point. With existing technologies, this is hardly manageable. In this respect, cash is still king.

It is often said that cash has high costs, and this is true (Krüger and Seitz, 2014). However, as it seems, the costs of digitized money are underestimated, perhaps to a large extent. In particular, to make digitized money cyber-secure and protect users from fraud may be very costly. Even in this respect cash could remain as an alternative.

Perhaps more important is another aspect. Imagine that in a digitized world a shortage or an interruption in the provision of electric power occurs or that backbones of the internet break down. It is well-known that technical systems require backup systems that are started automatically if the main system fails. It is not clear what kind of backup system is planned in a world of digitized money. It does not seem too far-fetched to assume that cash could be such a backup system because it does neither require electric power nor the internet for its functioning.[5]

Last, but not least, it is not very likely that banknotes would disappear completely, even if they were declared illegal. As is well-known, D-Mark banknotes circulate in billions in several countries (for instance, see Seitz, 1995; Deutsche Bundesbank, 2002). With digitized money, people will still hoard cash in order to pay anonymously for goods and services, outside of official markets and for illegal transactions. Moreover, they may insure themselves against the loss of digitized money. The result would be a world with two monetary circuits: an official one and a "subterranean" one (see *Figure 5*). Of course, the two monetary circuits would be connected with each other. The economic theory of black markets (see, for instance, Boulding, 1947; Das Gupta, 1950) demonstrates how such interconnected markets work. They are connected with each other by a kind of exchange rate, with respect to money: an exchange rate between digitized money and banknotes. If banknotes became illegal, it would not be possible to control the subterranean circuit (and the exchange rates would contain risk premiums). Moreover, it would be very difficult for monetary policy to account for effects of monetary policy measures in the subterranean circuit.

The subterranean part of the circuit in *Figure 5* could function without any institution as, for instance, a central bank. Cigarette currencies, the pirate money in Somalia (Krabbe, 1996) and many others are examples for subterranean monetary

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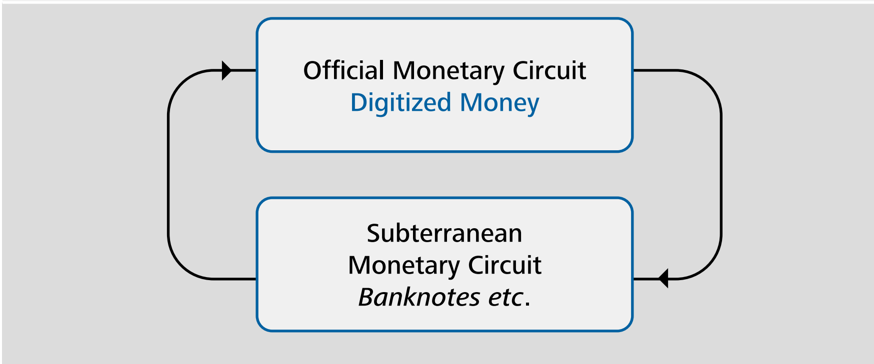
5 Another example for the longevity of „antiquated" technical devices is the programming language COBOL (common business-oriented language). Although there are many presumably superior programming languages, in over 60% of all organizations COBOL is the dominant or even the only programming language (Mitchell, 2006; Wikipedia, COBOL, 2019b).

Digitized money with a subterranean monetary circuit Figure 5



Source: Own depiction

circuits that worked well without a central coordination. Moreover, subterranean monetary circuits are (more or less) integrated in the economic circular flow of an economy. Put differently, the latter are components of the economy as a whole.

In a sense, the subterranean monetary circuit depicted in *Figure 5* may play a role in the "reswitching" from digitized money back to cash money. To see this, note that all transactions with digitized money will be observable. In a benevolent society with strict enforcement of privacy protection rules, this might not cause any serious problems. However, there is no guarantee at all whether over time authorities can be prevented from using the wealth of information that is stored in transaction data. For instance, to look for tax fraud and other illegal transactions, authorities may skim through the data by applying methods of so-called predictive analytics. As is well-known, such methods find an awful lot of false-positive results (Ellenberg, 2014, pp. 166 ff., with respect to false-positives in terrorism prevention via Facebook account analysis). The latter means that most of the transactions detected are legal ones. Nevertheless, the persons involved are suspected for committing a crime.

If the latter effects occur quite often, it might be decided that either anonymous digital money is allowed or people themselves "reswitch" to cash. This reswitching is the easier the larger the volume of banknotes that still exists. Moreover, even if no banknotes exist, it is easy to provide substitutes. For instance, gift vouchers of very big retailers may circulate as cash. As pointed out by John R. Searle (2017), acceptance creates money. If there is a need for cash, it will be created. Central banks or states are not necessarily required. In this respect, Georg Friedrich Knapp's (1905) "State Theory of Money" is wrong.

6. Conclusions

In this paper, the future of cash payments is studied. To do this, two not yet applied theories are used: Kranzberg's technology "laws" and Polanyi's "tacit dimension of knowledge". Kranzberg's technology laws are applied to define the conditions for completeness of a new technology. Four aspects are accounted for: the completeness of a technology itself, the completeness of the complementary infrastructure, of social (conflict resolving) institutions and of the legal framework. The digital economy is incomplete concerning all of these aspects, as shown, for instance, by DESI of the European Commission. Moreover, digitized money is even more incomplete as there exist neither a technical standard for these payment methods nor are the relevant infrastructure, the social institutions and the legal frameworks established.

In addition, the tacit knowledge of an everyday application of digitized money is lacking. Although several forms of such payment methods exist, none of them is dominant and none of them is everywhere available. As a consequence, experience and learning-to-use is not possible on a large scale. Quasi-automatic application of the existing devices is not possible in such a context.

As a preliminary result one can say that digitized money is not yet ready to substitute cash because of its Kranzberg incompleteness and the lack of tacit knowledge for quasi-automatic application.

However, even if the digitized economy and digital money are sufficiently Kranzberg complete, and if tacit knowledge for the application of digitized money is available, it is not very likely that cash (in the form of banknotes) will completely disappear. There are good reasons that cash will remain as a backup technology for digital money, as well as a method for paying with privacy protection. The latter may be required because it is very difficult, if not impossible, to guarantee that digital payments will not be observed and stored. Put differently, the availability of a non-observable payment method could prevent authorities from using data created by digital transactions.

Even if cash was banned officially and all banknotes disappeared, the reappearance of other forms of "cash" would be easy. The reason is that, e.g., gift vouchers of large-scale retailers could be used for "cash" payments. In other words, if cash is demanded in a society it will (re)appear. In this sense, it is impossible to destroy cash–as long as it is demanded by economic subjects. This is the ultimate limit of digitized money.

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Stefan Hardt
Concluding Remarks

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Director General Cash Management
at Deutsche Bundesbank

Ladies and gentlemen,

the past few days were full to the brim with various presentations and intense discussions. There is one thing we can say for sure: Cash is on its way, onwards into the future. After all, it has been shown that even though banknotes and coins may be slowly on the retreat at the point-of-sale, they are still an important and widely accepted means of payment.

Even the title of our conference reflects this: We have moved on from 2017's "War on Cash" to this year's topic where payment diversity is a given. However, we wouldn't have been able to take such a deep look into the various topics without our participants, who have actively shaped the course of this conference.

By presenting the results of intense analysis and sharing various opinions on cash, our economic as well as academic knowledge have been sharpened. In this regard it is especially a pleasure to reflect on the panel discussion which Johannes, Coen, Lars and Bill brought to life with their valuable contributions. After their keynote speeches in the morning it was splendid to see that everyone could find himself and his core topics in the discussion again:

Johannes highlighted the ongoing high demand for cash and that it is far from perishing, contrary to all swan songs. Coen underlined this statement and also mentioned the benefits cash has, for example as a fall-back-option for electronic payment systems. However, one of the topics I expect to gain significance is the question who should bear the costs of cash–banks, governments or consumers. An answer for this is not easy to be found, and it will be interesting to see how the accompanying discussion may gain pace in the next years.

Another important topic was the question which role high denominations may play–the discussion regarding the 500€-banknote appears immediately in my mind. And large denominations could be more important in an international environment than we might be conscious of, as Lars mentioned. After all, the usage as a store of value is what leads to widespread or even global trust in a currency. And especially Lars' remarks regarding monetary policy and a possible cash abolishment were particularly interesting, whereas I fully agree:

A cash abolishment is not a magical tool that will immediately solve the problems monetary policy is currently facing. Furthermore, it was also delightful to listen to Bills speech. Financial inclusion is gaining more and more importance, and even in the US are several millions of unbanked households which almost exclusively rely on the availability of cash.

And of course, as a cash enthusiast myself, it was relieving to be reinforced in my observation that new payment methods are not outright replacing cash. Instead, it's more of an additive process which once again reflects our conferences theme.

Or, to quote Bill again: 'Back to the future–it's cash!' And I can promise you without the slightest doubt: Paying by cash is not only easy, but also fast.

This has been proven in one of over twenty studies and research results which have been presented since yesterday. And we had an extraordinary bandwidth to cover this year: The topics ranged from microeconomic evidence on payment behaviour, consumer habits and cash demand to the full extent of the macroeconomic research. While research there focussed on cash demand, migration and banknote circulation forecasts, the darker sides of cash and its role in the shadow economy have also not been spared.

And today we were finally able to gain a deeper look into the possible fate of cash in the future, whereas I expect it might look way brighter than some may guess. Overall, we had the possibility to examine cash from a multitude of different angles. Some were based on a purely theoretical basis where others dipped into the practical sphere which showed that research is without a doubt able to have an impact on the real world. For example, I am one hundred per cent sure that all of us are now perfectly prepared to identify a genuine banknote in a split second. However, without appropriate 'preconditions' we would not have been able to dive this deep into the numerous cash related issues.

I would therefore like to offer my sincerest gratitude to all those who contributed to this conference. First and foremost: the speakers who presented their topics in such interesting and enthusiastic ways which allowed us to broaden our minds and deepen our knowledge have to be appreciated. Especially I would like to thank our Guests of Honour from the Netherlands, which enriched the conference with their hands-on topics. Furthermore the session moderators need to be recognized who ensured that their sessions went smoothly while keeping a keen eye on the clock at all times. Of course, our conference was also heavily dependent on all participants who asked questions and provided their active contribution.

Finally, I would also like to thank the organisational team which ensured perfect frame conditions which made the conference possible. But, as a German saying goes: 'All good things have to come to an end'.

It is therefore both pain and pleasure for me to end this conference. But do not worry: our fourth International Cash Conference will not be the last. Indeed, we will have another one in two years, and we will see how cash, its perception and underlying research have developed in the meantime to further facilitate academic exchange. I hope you enjoyed your stay here as much as I did mine. Please also remember that you are cordially invited to the lunch afterwards before heading towards the train station or the airport, if your timeframe allows to do so. Have a safe and comfortable journey back home and hopefully we will be able to see each other again in 2021.

Thank you very much and goodbye.

Johannes Beermann
Heads and tails–cash in the age of digitalisation

Johannes Beermann
Member of the Executive Board of Deutsche Bundesbank

1. Introduction

Ladies and gentlemen,

Welcome to the Seehaus right at the heart of the English Garden. This park is a true landmark of the city of Munich, with a design inspired by British landscape architecture.

It probably comes as no surprise that football–another at least originally English pastime–is popular around here as well. Of course, "kicking a ball" with friends in a park such as the English Garden is a more informal affair than the matches you might see in the professional football leagues, where the stakes are arguably much higher. But the basic principles of football apply everywhere. The direction of play is the first decision to be made before any match can begin. Depending on the position of the sun or the direction of the wind, the choice of which goal to defend first could make a difference to the game's outcome. A neutral mechanism needs to be put in place to decide who obtains this "first mover advantage". A coin toss is one such mechanism. The coin is considered "fair" if both events–the coin landing on heads or the coin landing on tails–have an equal probability of occurring.

In the history of minting, heads on the obverse and tails on the reverse have emerged as the two sides shown on coins which serve as legal tender. Although the details on each side differ at first sight, they are closely related. To "coin" a well-known expression, heads and tails are literally two sides of the same coin. Together, they complete the coin, which also means both sides have to be taken into consideration.

In the world of payments, that is precisely what central banks do. On the one hand, we provide payment systems that function purely electronically while, on the other hand, we take part in the production and distribution of physical cash. In the prevailing set-up, one aspect of payments cannot work without the other.
Digital payments are in a state of flux. New competitors enter the market, at times trying to disrupt existing structures.

The direction of play remains unclear at this stage. It may be that the rise of one form of digital payment will lead to the fall of another. It may also be that physical cash is used to a lesser and lesser extent until it effectively fades from existence, at least as far as transactions are concerned.

None of us have a crystal ball to tell us how the match will end. But we can look at existing evidence.

In my brief remarks this evening, let us turn to the hypothetical question: how would the coin toss change, if one of the sides were to vanish?

2. Supply and demand factors behind cash usage

Ladies and gentlemen,

In Germany, cash remains as popular among private households as ever. If asked directly, 88% of German households would be in favour of keeping the option of using cash for everyday transactions.[1]

This generally "cash-loving" attitude is reflected in the data on actual cash usage. We know from our own analysis that 74% of all point-of-sale transactions are made using banknotes and coins.[2]

But this number is declining–albeit gradually and from a high level by international standards. In some countries, cash usage is already significantly lower than in Germany.

In principle, the declining use of cash could be driven by weakening demand. This could occur if alternative means of payment were to appeal more in relative terms to private households. We as central bankers take a neutral stance towards such a consumer-driven process.

However, the declining usage of cash could also be driven by a weakening supply as the existing cash infrastructure erodes. Such adjustments could stem from both private and public entities and could hamper the adequate provision of cash. The reasons for this may be complex, yet the implications would be straightforward: households would have to adjust, too.

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1 Deutsche Bundesbank (2018), Payment behaviour in Germany in 2017–fourth study of the utilisation of cash and cashless payment instruments.

2 Ibid.

Once obtaining cash simply becomes "too cumbersome", switching to electronic alternatives is the rational decision, but it means less choice and it may pose several social challenges:

- Think of ensuring financial inclusion in an ageing population.
- Think of providing a non-electronic alternative in times of political crisis or in the event of large-scale cyber attacks.

Any rational decision is preceded by a cost-benefit analysis. While we may see the benefits of different payment methods, we also need to understand their underlying cost structures.

We looked in a recent study at the overall transaction costs of cash compared to debit and credit card payments in the German retail sector.[3]

Cash did turn out to be the most cost-efficient payment instrument for retailers when accounting for cost drivers such as cash handling, fees for card payments and payment infrastructure provision.

But, looking ahead, several factors need to be understood better. To name just a few:

- How is the increasing use of contactless payments impacting on transaction costs across the various payment instruments?
- How are other actors in the cash cycle, most notably financial institutions, dealing with their cost structures?

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3 Deutsche Bundesbank (2019), The cost of payment methods in the retail sector, Monthly Report, June 2019, pp. 65-79.

– What is the market price of personal information? Or, to put it more directly: do digital forms of payment that contain traces of individual data generate social costs that need to be accounted for in future cost comparisons?

It is obviously hard to disentangle supply and demand-side drivers in economics. Moreover, both drivers are likely to be mutually reinforcing.

But to the extent that declining cash usage is driven by supply-side adjustments, central banks can no longer remain neutral. With one side dominating, the coin becomes biased.

Being neutral with regard to consumer choices does not imply being passive with regard to providing an adequate cash infrastructure. This is especially relevant given that the only viable alternative to physical cash is introducing some form of central bank digital currency. But, in the euro area at least, I cannot see this happening any time soon.

3. Conclusion

Ladies and gentlemen,
The coin is still spinning through the air, and two outcomes seem conceivable at this juncture.

– In the first scenario, private and public actors within the cash cycle take measures to ensure the adequate provision of cash in line with prevailing demand. As a result, the coin retains its current characteristics, encompassing both electronic and physical forms of payment.
– In the second scenario, the physical side of the coin increasingly starts to resemble the digital side. In effect, the coin becomes one-sided.

One-sided coins are not without historical precedent. Some 800 years ago, a variety of pfennig coinage dominated monetary circulation in German-speaking areas. Known as bracteates, these coins were embossed on one side and often hollow on the other.

The relatively simple technique employed to make them was also reflected in their limited function as a store of value. In fact, these one-sided coins were infamous for their frequent and sharp devaluations. As a result, stable coinages were introduced in the 14th century. Those were, of course, two-sided and have become a true symbol of monetary stability that has endured to this day.

Central bank money is the most recognisable means of payment. It is the local unit of account and the only legal tender. Ensuring its adequate supply is a key task for central banks, which we need to fulfil at all times. As technologies advance and digital forms of money increasingly enter the field, policymakers will not be able to remain "on the sidelines".

There are two sides to every coin, after all. On that note, I would like to wish you all a very pleasant and interesting evening. You still have to decide between an excellent red and an equally excellent white wine. The choice is yours. Perhaps a coin toss will help.

Thank you.

Stefan Hardt
A chief cashier’s worst nightmare

Stefan Hardt
Director General Cash Management
at the Deutsche Bundesbank

Ladies and gentlemen,

Before we enjoy dinner, I would like to take the opportunity to welcome you to our cash conference and to this splendid location. We have, I think, already seen many interesting presentations. This conference gives us lots of new insights into various topics and helps us in our daily business. But of course, the conference programme does not cover all of the operational challenges we face. So, I want to take the chance to extend the agenda this evening. But don’t worry; I will not be giving you another scientific paper presentation. Over the next couple of minutes, I would like to take you on a brief imaginary journey through the worst nightmares of a chief cashier. Of course, this is meant slightly tongue-in-cheek, although the background to it is serious enough. Sometimes it seems that latent concerns and fears, unprocessed daily occurrences or even traumatic or traumatising events are buried deep in our sub-consciousness, and that they occasionally turn into nightmares. However, if you know what’s causing a nightmare, you can analyse the scenario that triggered it, identify weaknesses and take precautions–and, usually, the nightmares will go away again by themselves. Let us therefore take a look at the possible causes.

It is conceivable that more cash is required than the central bank is able to deliver. An empty vault at a central bank is a nightmare scenario, as I'm sure you will agree. One possible reason for that might be a loss of confidence in the solvency of a commercial bank. If customers lack confidence in the bank's ability to pay, the possibility of a bank run becomes a real threat. We saw such a tendency in Germany in October 2008. At that time, we experienced significant outflows of cash from our vaults. The extent of uncertainty and concern at the time–even at the Bundesbank and in the German Federal Government–can be judged from a televised address by Chancellor Merkel on 5 October 2008, in which she guaranteed, on behalf of the Federal Government, that the savings deposits of all individuals were safe. This quick and decisive response helped to get a critical situation under control and prevent a full-scale escalation. Demand for cash returned to a manageable level. But this episode from the recent past has shown me how quickly a bank run can develop, simultaneously causing a huge increase in the demand for cash. As central bankers, we need to do all we can to prevent the emergence of crises with economic causes, or, at the very least, to reduce their scale and impact. One remarkable lesson we have learnt from this crisis is that, in most cases, a crisis doesn't peak at the same time in the individual economies–there's normally a time lag. That's what makes close cooperation based on mutual trust between the individual countries so important.

Ladies and gentleman, if the demand for cash exceeds supply, this is a veritable nightmare scenario. But the opposite situation would also raise problems. If consumers significantly change their payment habits and demand much less cash, this could pose major challenges for me as head of the Bundesbank's cash department. The faster and the more marked the drop in demand for cash, the more acute the impact on us would be. At the Bundesbank, we have a branch network with currently 35 branches and well over 100 high-performance banknote processing machines. More than 2,000 jobs at the Bundesbank depend on cash, not least my own. A collapse in demand for banknotes, especially in terms of transaction balances, would very soon lead to significant overcapacities at the central banks and a corresponding need to adapt.

But what possible reasons are there for consumers in Germany to turn their backs on cash? One potential scenario would be if very high-quality counterfeits came into circulation. If consumers were to lose substantial trust in being able to pay for goods and services with their cash, they would quickly, and perhaps permanently, switch to using other means of payment. And counterfeit money, which consumers have difficulty in distinguishing from genuine currency, would very probably lead to such a loss of confidence. That is the reason why we in the Eurosystem are constantly striving to make life harder for counterfeiters by creating new security features. Yet, despite our best efforts, concerns about very high-quality counterfeits are not entirely unfounded. I don't want to talk about the "superdollar" in the 1990s or the counterfeit British pound notes produced under the National Socialists during the Second World War, which I'm sure you are all aware of ("Operation Bernhard"). No, even more fascinating in my opinion is the story of the 28-year-old Portuguese man, Alves dos Reis, who in 1925 managed to bring counterfeit banknotes into circulation in Portugal. At the time, nearly every second 500 escudo banknote in circulation was a fake. Using a fake contract, Alves dos Reis commissioned an official banknote printing works in England to produce and deliver banknotes. As a result, it was virtually impossible to distinguish the counterfeits from genuine banknotes.[1] A scenario of this kind is enough to give anyone sleepless nights. Central banks, printing works, manufacturers of banknote paper, inks and

1 The description of the banknote crisis in Portugal is based on "The effects of the 1925 Portuguese bank note crisis", London School of Economics, Working Paper No 82, 2004.

other security features are all needed to put effective precautionary measures in place. But how exactly do we protect ourselves against a similar scam? Above all, by not talking publicly about our protective mechanisms.

But many other possible sources of nightmares spring to mind. In 2006, for example, there were several thousand cases in Germany where the banknotes that consumers withdrew from ATMs crumbled after coming into contact with human skin. At first, we were in the dark as to what the cause might be. Investigations revealed that the banknotes bore traces of sulphuric acid. The acid caused the cotton in the banknotes to disintegrate as soon as they came into contact with human perspiration. It is still unclear today how the sulphuric acid came to be on the banknotes in the first place. One possible cause might have been the incorrect use of detergents. Fortunately, the phenomenon of the self-destructing banknotes disappeared again by itself.

It will probably never be possible to prevent these and similar situations and problems entirely. The best protection in my opinion is, first and foremost, to ensure the high quality of the product. And we in the Eurosystem, together with the banknote producers, are working to maintain their high quality and constantly improve it.

So, to summarise: there are plenty of things that could give a chief cashier nightmares he might talk about, thus preventing you from enjoying your dinner. I've mentioned a few examples of what can cause an unexpectedly sharp increase in the demand for banknotes or an abrupt decline in demand. But it is possible to plan for these and many other scenarios, knowing full well that the next crisis or the next challenge does not necessarily have to be a repeat of the past. I dare say it's highly likely that there will be new challenges in future that we cannot at present conceive of, and that their magnitude may well surprise us. And I am pretty sure we will find some of these topics on conference agendas in the coming years.

However, if, in good conscience, contingency plans are put in place for potentially risky scenarios, you are assured a good night's sleep. Or at least, you'll have improved your chances of sleeping well. On that note, let us now enjoy this evening.

Thank you for your attention.
Cheers.

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Programme

Monday, 09 September 2019

19:00 Welcome reception at the Hotel Sofitel Bayerpost in Munich

Tuesday, 10 September 2019

Moderation: Jelena Stapf

09:00 – 09:15	**Welcome remarks** Johannes Beermann (Member of the Executive Board of Deutsche Bundesbank)
09:15 – 09:45	**Introduction and Quick scan** Coen Voormeulen (De Nederlandsche Bank)
09:45 – 10:30	**Keynote:** Lars Feld
10:30 – 11:15	**Keynote:** Bill Maurer
11:15 – 12:15	**Panel Discussion**
12:15 – 12:30	Group photo
12:30 – 13:45	Lunch

Session I: Guest of Honour – The Netherlands

Moderation: Hans de Heij

13:45 – 14:05	**Modelling user needs of payment instruments** Hans de Heij (De Nederlandsche Bank)
14:05 – 14:35	**Does banknote authentication need time and touch?** Frank van der Horst (De Nederlandsche Bank)
14:35 – 15:00	**Life cycle assessment of cash payments in the Netherlands** Nicole Jonker (De Nederlandsche Bank)
15:00 – 15:15	**Design examples of future cash** Igo Boerrigter (De Nederlandsche Bank)
15:15 – 15:40	Coffee break

Interactive session

Moderation: Jelena Stapf

15:40 – 16:20	**Moderated voting and discussion:** The future of high denomination banknotes – perspective of different countries

Tuesday (continued)

17:15 – 18:45 Guided tour of the Englischer Garten
19:00 – 21:30 Dinner in the Pavilion of Seehaus im Englischen Garten
Speaker: Johannes Beermann
(Member of the Executive Board of Deutsche Bundesbank)

After dinner Return transfer to Hotel Sofitel / Maritim

Wednesday, 11 September 2019

	Session II: Microeconomic evidence on payments (Moderation: Heike Wörlen)	Session III: Macroeconomic evidence on cash demand and circulation (Moderation: Helmut Stix)
09:00 – 09:45	**New evidence on the demand side of cash payments** Jörn Tenhofen (Swiss National Bank)	**Model of banknotes migration - case of Poland** Arkadiusz Manikowski (Narodowy Bank Polski)
09:45 – 10:30	**What could induce Polish consumers to reduce cash payments?** Janina Harasim (University of Economics in Katowice) Monika Klimontowicz (University of Economics in Katowice)	**Coin migration between Germany and other euro area countries** Matthias Uhl (Deutsche Bundesbank)
10:30 – 11:00	Coffee break	
11:00 – 11:45	**Changes in U.S. consumer payments: A study of the diary of consumer payment choice** Shaun O'Brien (Federal Reserve Bank of San Francisco)	**Cash in circulation and the shadow economy: An empirical investigation for euro area countries and beyond** Friedrich Schneider (Johannes Kepler University Linz) Franz Seitz (Weiden Technical University of Applied Science)
11:45 – 12:30	**Cash use and financial literacy** Kim Huynh (Bank of Canada) Gradon Nicholls (Bank of Canada)	**Cash demand in the shadow economy in Germany** Nikolaus Bartzsch (Deutsche Bundesbank)

Wednesday, 11 September 2019 (continued)

12:30 – 14:00	Lunch	
	Session II (continued)	**Session III (continued)**
14:00 – 14:45	**The usage of cash as a store of value in Germany** Susann Sieber (Deutsche Bundesbank)	**A tale of two countries: Cash demand in Canada and Sweden** Walter Engert (Bank of Canada) Ben Fung (Bank of Canada)
14:45 – 15:30	**How does liquidity affect consumer payment choice?** Joanna Stavins (Federal Reserve Bank of Boston)	**Fiscal controls, payment limits and the demand for cash** Edoardo Rainone (Banca d'Italia)
15:30 – 16:00	Coffee break	
16:00 – 16:45	**Cash usage trends in Japan: Evidence using aggregate and household survey data** Hiroshi Fujiki (Chuo University, Japan)	**The role of cash in the shadow economy** Johana Cabinakova (Deutsche Bundesbank) Fabio Knümann (Deutsche Bundesbank)
17:30 – 18:45	Guided tour of Paulaner Bräuhaus incl. tasting	
19:00 – 21:30	Dinner at Valentinsaal of Wirtshaus in der Au Speaker: Stefan Hardt (Director General Cash Management, Deutsche Bundesbank)	
After dinner	Return transfer to Hotel Sofitel / Maritim	

Thursday, 12 September 2019

	Session II (continued)	Session III (continued)
09:00 – 09:45	**From cash to choice: Uptake of digital financial services in the Netherlands** Gawain Lynch (Canela) Erin Taylor (Canela)	**Forecasting euro banknote circulation developments: An empirical analysis** Dieter Gerdesmeier (European Central Bank) Barbara Roffia (European Central Bank)
	Session II (continued)	**Session III (continued)**
09:45 – 10:30	**The costs of cash payments in the retail sector** Johana Cabinakova (Deutsche Bundesbank) Fabio Knümann (Deutsche Bundesbank)	**Cash abolition to overcome the zero lower bound: A welfare-theoretic analysis** Gerhard Rösl (OTH Regensburg) Franz Seitz (Weiden Technical University of Applied Science)

10:30 – 10:55 Coffee break

Session IV: The digital future of cash

Moderation: Johana Cabinakova

10:55 – 11:40 **Cash use across countries and the demand for central bank digital currency**
David Humphrey (Florida State University)
Tanai Khiaonarong (International Monetary Fund)

11:40 – 12:20 **The future of cash in a digitized economy**
Hanno Beck (Pforzheim University)
Aloys Prinz (University of Münster)

12:20 – 12:50 **Neurometrics applied to banknote and security features design**
Fernando Leon (Banco de EspaĒa)

12:50 – 13:10 **Concluding remarks**
Stefan Hardt (Director General Cash Management, Deutsche Bundesbank)

13:10 – 14:00 Lunch buffet

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