DEUTSCHE
BUNDESBANK
EUROSYSTEM

Discussion Paper

Deutsche Bundesbank
No 03/2020

The power of forward guidance in a quantitative TANK model

Rafael Gerke
Sebastian Giesen
Alexander Scheer

Deutsche Bundesbank, Wilhelm-Epstein-Straße 14, 60431 Frankfurt am Main,
Postfach 10 06 02, 60006 Frankfurt am Main

Tel +49 69 9566-0

Please address all orders in writing to: Deutsche Bundesbank,
Press and Public Relations Division, at the above address or via fax +49 69 9566-3077

Internet http://www.bundesbank.de

ISBN 978–3–95729–664–1 (Printversion)
ISBN 978–3–95729–665–8 (Internetversion)

Non-technical summary

Research question

Interest rate forward guidance has become an important monetary policy tool in recent years. However, traditional representative agent New Keynesian models tend to grossly overestimate the impact of forward guidance on the economy due to strong intertemporal substitution. With heterogeneous households, intertemporal substitution can be reduced. Hence, we quantify to what extent hand-to-mouth households can help to mitigate the power of forward guidance compared to a representative agent model.

Contribution

We build a medium-scale two-agent New Keynesian model featuring Ricardian and hand-to mouth households. The model includes a banking sector and is estimated on eight euro area time series. We analyze the quantitative importance of hand-to-mouth households to dampen the power of forward guidance relative to a representative agent model. In addition, we illustrate an interaction of forward guidance with asset purchases, as observed in recent years.

Results

We obtain three main results. (i) The power of forward guidance is attenuated, if there is an empirically realistic countercyclical redistribution across Ricardian and hand-to-mouth households. There are two opposing effects regarding the power of forward guidance when the economy features hand-to-mouth households. First, the aggregate intertemporal substitution is lower, as hand-to-mouth households do not smooth consumption over time (direct effect). Second, the aggregate marginal propensity to consume is higher, since hand-to-mouth households spend all their income (indirect effect). Due to redistribution across households, the direct effect outweighs the indirect one. (ii) We quantify the conditions under which either the direct or indirect effect dominates. With no redistribution, the impact of forward guidance is indeed amplified. (iii) The interaction of forward guidance with asset purchases gives rise to non-linear effects that depend on the horizon of forward guidance.

Nichttechnische Zusammenfassung

Fragestellung

Die Kommunikation über die zukünftige Ausrichtung der Geldpolitik (Forward Guidance) ist in den letzten Jahren zu einem wichtigen geldpolitischen Instrument geworden. Das neukeynsianische Standardmodell mit einem repräsentativen Agenten impliziert jedoch aufgrund starker intertemporaler Substitution unrealistisch große Auswirkungen von Forward Guidance. Mit Hilfe heterogener Haushalte lässt sich die intertemporale Substitution abschwächen. Daher untersuchen wir, inwieweit die Einführung eines zweiten Haushalts der "von der Hand in den Mund" lebt (*hand-to-mouth*), dazu beitragen kann, die Stärke von Forward Guidance im Vergleich zum Standardmodell zu verringern.

Beitrag

Wir formulieren ein quantitatives neukeynesianisches Zwei-Agenten-Modell mit ricardianischen und hand-to-mouth Haushalten. Das Modell verfügt über einen Bankensektor und wird basierend auf acht Zeitreihen des Euroraums geschätzt. Wir untersuchen inwieweit die Effekte von Forward Guidance im Zwei-Agenten-Modell im Vergleich zum Standardmodell gedämpft werden können. Darüber hinaus analysieren wir mögliche Wechselwirkungen von Forward Guidance mit Anleihekäufen, wie sie in der Vergangenheit beobachtet wurden.

Ergebnisse

Unsere Analyse des Zwei-Agenten-Modells führt zu drei wichtigen Ergebnissen. (i) Die Stärke von Forward Guidance wird gedämpft, wenn eine empirisch realistische antizyklische Umverteilung zwischen den Haushalten unterstellt wird. Die Modellierung von hand-to-mouth Haushalten verändert die Stärke von Forward Guidance in zwei gegensätzliche Richtungen. Erstens, die intertemporale Substitution verringert sich, weil hand-to-mouth Haushalte ihren Konsum nicht glätten (direkter Effekt). Zweitens, die aggregierte marginale Konsumneigung erhöht sich, da hand-to-mouth Haushalte ihr gesamtes Einkommen konsumieren (indirekter Effekt). Aufgrund der antizyklischen Umverteilung zwischen den Haushalten überwiegt der direkte Effekt. (ii) Wir quantifizieren unter welchen Bedingungen der direkte Effekt größer ist als der indirekte. Ohne Umverteilung wirkt Forward Guidance stärker als im Standardmodell. (iii) Wir veranschaulichen eine nicht-lineare Wechselwirkung zwischen Forward Guidance und Anleihekäufen, die vom Horizont der Forward Guidance abhängt.

DEUTSCHE BUNDESBANK DISCUSSION PAPER NO 03/2020

The Power of Forward Guidance in a Quantitative TANK Model*

Rafael Gerke Sebastian Giesen Alexander Scheer

February 11, 2020

Abstract

We quantify the macroeconomic effects of interest rate forward guidance in an estimated medium-scale two-agent New Keynesian (TANK) model. In general, such models can dampen or amplify the power of forward guidance compared to a representative agent model. Our empirical estimates indicate a dampening, as there is sufficient countercyclical redistribution. An interaction with asset purchases gives rise to non-linear effects that depend on the horizon of forward guidance.

Keywords: Forward Guidance, Hand-to-mouth households, Redistribution, Bayesian Estimation, Asset purchase program

JEL Classification: E44, E52, E62

*Rafael Gerke (e-mail: rafael.gerke@bundesbank.de), Sebastian Giesen (e-mail: sebastian.giesen@bundesbank.de), Alexander Scheer (e-mail: alexander.scheer@bundesbank.de): Deutsche Bundesbank, Monetary Policy and Analysis Division, Wilhelm-Epstein-Strasse 14, 60431 Frankfurt, Germany. We thank an anonymous referee for many constructive comments and valuable suggestions. We also thank Felix Geiger, Daniel Kienzler, Vivien Lewis, Matija Lozej, Jean-Guillaume Sahuc, Andreas Schaab, Harald Uhlig and Andreas Worms, as well as seminar participants at the Asian Meeting of the Econometric Society 2019, the 25th International Conference in Computing in Economics and Finance and the EEA-ESEM 2019 for helpful comments. The views expressed in this paper are those of the authors and do not necessarily reflect those of the Deutsche Bundesbank or the Eurosystem.

1 Introduction

Interest rate forward guidance has become an important tool for central banks to enhance the effectiveness of monetary policy at the zero lower bound (Fed, 2008; Deutsche Bundesbank, 2013). In this paper, we quantify the macroeconomic effects of forward guidance within an estimated medium-scale two-agent New Keynesian (TANK) model. This framework serves as a simple approximation to a fully-fledged heterogeneous agent New Keynesian model (see for instance Bilbiie, 2019b; Debortoli and Galí, 2018). Such models can dampen the strong aggregate effect of forward guidance, that is inherent in many complete market or representative agent models. One reason is that full heterogeneity features lower intertemporal substitution of households, which reduces the responsiveness of present macroeconomic aggregates to changes in future interest rates (McKay, Nakamura and Steinsson, 2016; Bilbiie, 2019a).[1]

As is already well known, strong intertemporal substitution is caused by forward-looking behavior (Del Negro, Giannoni and Patterson, 2015; Kiley, 2016).[2] One possibility to attenuate the forward-looking behavior within the model would therefore be to introduce some heterogeneity on the households side, in which one type of household behaves "as usual" and another type does not smooth consumption intertemporally. These latter agents are typically called hand-to-mouth households, which have no access to financial markets and can thus neither borrow nor save. Therefore, they are not forward-looking.

However, having a model with two agents does not automatically imply a reduction in the power of forward guidance compared to the representative agent model. As shown analytically by Bilbiie (2008, 2019b), the overall strength of intertemporal substitution depends on the elasticity of the hand-to-mouth agents' income to aggregate income. The reason is that this elasticity shapes the relative strength of the so-called direct and indirect effects of forward guidance (for such a distinction, see also Kaplan, Moll and Violante, 2018).

The direct effect of changes in interest rates refers to the impact in the absence of changes in household income / general equilibrium and usually works via in-

[1] This introduces some form of discounting into the Euler equation (McKay, Nakamura and Steinsson, 2017). Discounting can be also achieved through deviations from rational expectations, as for instance with incomplete information (Angeletos and Lian, 2018), bounded rationality (Gabaix, 2018) or level-k thinking (García-Schmidt and Woodford, 2019).

[2] Take as a baseline the following forward guidance scenario: the central bank pegs the interest rate at a low level for the next T quarters, which will lead to an expansion and inflation in all T quarters. Now suppose that the peg is extended by one period, i.e. until $T+1$. This will lead to a stimulus in $T+1$ which raises inflation in $T+1$ and thus lowers the real rate in T. Since monetary policy is constrained by the peg there is a *further* stimulus in period T which also raises inflation in T and lowers real rates in $T-1$. This process continues until the present. As monetary policy does not counteract any stimulus until $T+1$, the cumulative effect of a future expansion rises more, the longer the peg and thus the further away the marginal extension. If monetary policy would not be constrained by a peg, it would simply raise its policy rate and thus limit the aggregate response.

tertemporal substitution. As an example, when nominal interest rates fall, all else equal, real rates fall as well. This induces households to save less and to increase their demand for consumption. Complementary to this direct effect is the indirect effect of monetary policy. It operates through the general equilibrium increase in labor demand and thus income which is necessary to satisfy the increase in consumption demand. Higher household income raises consumption even further and so on. As discussed in Kaplan et al. (2018) or Luetticke (2019), in representative agent models most of the transmission of monetary policy on output and inflation is due to the direct effect of intertemporal substitution. In contrast, in heterogeneous agent models the indirect effect dominates.

Taken together, the introduction of hand-to-mouth households can increase or decrease the power of forward guidance. This depends on which of the two effects dominates. As Bilbiie (2019b) shows analytically for a simple two-agent model, the introduction of hand-to-mouth households reduces the direct effect of forward guidance, as only a smaller fraction of households smooths intertemporally. However, it enhances the indirect, i.e. general-equilibrium effect, since the higher marginal propensity to consume of hand-to-mouth households raises per se their own (and thus total) consumption. If, in addition, their income "over-reacts" to changes in aggregate income (which happens with no or too little redistribution), the amplification through the indirect effect dominates and the power of forward guidance increases compared to the representative agent model.[3]

Our contribution is to illustrate under which conditions the direct or indirect effect dominates in an empirically realistic two-agent model. We estimate a medium-scale version on eight euro area time series and evaluate the quantitative implications of hand-to-mouth households to dampen the power of forward guidance. For plausible ranges of parameters the power of forward guidance is indeed reduced compared to our representative agent benchmark version. The amount of attenuation depends on the degree of *countercyclical* transfers (similar to automatic stabilizers in McKay and Reis, 2016) and the share of hand-to-mouth households. If there is no or "too little" redistribution, our model amplifies the impact of forward guidance on the economy relative to the benchmark representative agent model. Moreover, we evaluate the combined effects of forward guidance and the Eurosystem's asset purchase program. We find that the combined impact of asset purchases and forward guidance is higher than the sum of each policy used in isolation. This difference increases with the horizon of forward guidance.

Although our two-agent model can dampen the power of forward guidance, it does not feature a mechanism to solve the so-called forward guidance puzzle: an unreasonably large response of inflation and output that rises exponentially if the horizon of interest rate guidance is extended.[4] This paper rather emphasizes

[3]Note that Kaplan et al. (2018) point to fiscal policy as an important driving force in their heterogeneous agent model.

[4]A possibility to solve the forward guidance puzzle is to include uninsurable income risk, an essential feature of heterogeneous agent models (e.g. McKay et al., 2016; Werning, 2015).

a simple, yet empirically realistic, extension of medium-scale New Keynesian models – heterogeneity and countercyclical transfers – that allows to substantially tame the power of forward guidance.[5] For realistic values of the share of hand-to-mouth households and countercyclical transfers our model attenuates the impact of forward guidance by up to 40% compared to the representative agent version.[6]

The next section describes the framework used with a special emphasis on the two crucial features of rule-of-thumb households and the transfer scheme. Section 3 gives an overview of the data and the estimation results. Section 4 describes the forward guidance simulations conducted in this paper before the final section concludes.

2 Framework

The model builds heavily on the medium-scale New Keynesian model of Carlstrom, Fuerst and Paustian (2017) that features a rich financial sector which allows to analyze the effects of unconventional monetary policy measures. We augment their framework by rule-of-thumb consumers in the spirit of Galí, López-Salido and Vallés (2007) and a simple transfer rule (Bilbiie, 2008). The economy consists of households, firms and a banking sector, which will be explained in detail below. In a nutshell, real investment is ultimately financed by financial intermediaries, whose lending capacities are constrained by their net worth.

2.1 Households

The economy is populated by two types of households: A measure $1 - \lambda$ of households has complete access to financial markets and can smooth consumption through short-term deposits and the accumulation of real capital – we call them Ricardian households. The remaining fraction λ has no access to financial markets (it can neither borrow nor save) and consumes its wage income and

Bilbiie (2019a) shows how uninsurable income risk generates discounting (or compounding) in the Euler equation and that this can solve the forward guidance puzzle if it is combined with procyclical income inequality (i.e. hand-to-mouth households income decreases/increases relative to unconstrained households income in a boom/recession). Acharya and Dogra (2019) show within a setup of special preferences that adding (procyclical) income risk can solve the forward guidance puzzle even absent heterogeneity in the marginal propensities to consume.

[5] The odds ratio favors our two-agent model over its representative agent version essentially with probability one.

[6] The richer model allows us to show that the mere introduction of hand-to-mouth households can in principle attenuate the impact of forward guidance, i.e. without the necessity to introduce countercyclical transfers. For example, if wages are assumed to be very sticky (re-optimization only every 20 quarters), the (above mentioned) indirect effect is much weaker while the direct effect is still in place (for the implications of sticky wages and hand-to-mouth households, see Colciago, 2011).

transfers – we call them hand-to-mouth (rule-of-thumb or constrained) households.

Each Ricardian household maximizes lifetime utility

$$E_t \sum_{s=0}^{\infty} \beta^s d_{t+s} \left\{ \ln\left(C^o_{t+s} - hC^o_{t+s-1}\right) - B\frac{H^{1+\eta}_{t+s}}{1+\eta} \right\}, \tag{1}$$

where C^o_t denotes private consumption, h degree of habit, H_t the (individual) labor input (scaled by B to normalize labor input in steady state) and d_t a shock to the linearized discount factor given by:

$$d_t = (1-\rho_d)\ln(d) + \rho_d d_{t-1} + \epsilon_{d,t} \tag{2}$$

The budget constraint is given by

$$C^o_t + P^k_t I^o_t + \frac{D_t}{P_t} + (1+\kappa Q_t)\frac{F_{t-1}}{P_t} = w_t H_t + R^k_t K_t + \frac{D_{t-1}}{P_t} R^d_{t-1} + div_t - T^o_t + \frac{Q_t F_t}{P_t} \tag{3}$$

Households invest in real capital $P^k_t I_t$, save deposits $\frac{D_t}{P_t}$ and repay their outstanding debt including a coupon payment of 1, $(1+\kappa Q_t)\frac{F_{t-1}}{P_t}$ (see below).[7] They earn labor income $w_t H_t$ (to be specified below), a return on capital $R^k_t K_t$ and deposits $R^d_{t-1}\frac{D_{t-1}}{P_t}$ and dividends div_t net of taxes T^o_t (which consists of a lump-sum part and a re-distributive part, see section 2.5 for details). div_t includes dividends from the FI (div^{FI}_t), capital goods producer (div^{CP}_t) and intermediate goods producer (div^{IP}_t).
There is a need for intermediation through the financial system since all investment purchases of the household must beforehand be financed by issuing new investment bonds (hence, there is loan in advance constraint). The price of such bonds is denoted by Q_t and offers the following payment stream of the household, following Woodford (2001): $1, \kappa, \kappa^2, \ldots$ etc.[8] Let CI_t denote the number of new perpetuities issued in time t, then the household's stock of nominal liabilities F_t is given by

$$F_t = \kappa F_{t-1} + CI_t \;\Leftrightarrow CI_t = F_t - \kappa F_{t-1}. \tag{4}$$

The loan in advance constraint is then given by:

$$P^k_t I_t \leq \frac{Q_t CI_t}{P_t} \tag{5}$$

The law of motion for capital follows:

$$K_t = (1-\delta)K_{t-1} + I_t. \tag{6}$$

[7] Note that they have also access to short-term government bonds, but those are perfect substitutes with deposits. D_t can thus be interpreted as the households net resource flow into the FIs (Carlstrom et al., 2017).

[8] Due to the recursive structure, $\kappa^h Q_t$ is the time t price of such a bond that was issued in period $t-h$.

The representative Ricardian household therefore maximizes utility (1) subject to the budget constraint (3), the loan in advance constraint (5) and the law of motion for capital (6). The first order conditions are given by:

$$\Lambda_t = \frac{b_t}{C_t^o - hC_{t-1}^o} - E_t \frac{\beta h b_{t+1}}{C_{t+1}^o - hC_t^o} \tag{7}$$

$$\Lambda_t = E_t \beta \frac{\Lambda_{t+1}}{\Pi_{t+1}} R_t^d \quad \text{with} \quad \Pi_{t+1} = \frac{P_{t+1}}{P_t} \tag{8}$$

$$\Lambda_t M_t Q_t = E_t \frac{\beta \Lambda_{t+1} \left(1 + \kappa Q_{t+1} \mathrm{M}_{t+1}\right)}{\Pi_{t+1}} \tag{9}$$

$$\Lambda_t M_t P_t^k = E_t \beta \Lambda_{t+1} \left[R_{t+1}^k + M_{t+1} P_{t+1}^k \left(1 - \delta\right)\right] \tag{10}$$

with $M_t = 1 + \frac{\vartheta_t}{\Lambda_t}$ or $\Lambda_t M_t = \Lambda_t + \vartheta_t$. The first two equations comprise the typical Euler-equation for deposits, the third one for investment bonds. Note that the demand for capital (last equation) is distorted by the time-varying distortion M_t which depends on the multiplier of the loan-in-advance constraint (5). As discussed in great detail in Carlstrom et al. (2017), this distortion acts like a mark-up on the price of new capital and is basically the term premium that exists due to the segmented markets and the leverage constraint of the banks that limit the arbitrage across the term structure (see next subsection).

The budget constraint of hand-to-mouth agents is much simpler as they neither borrow nor save and only consume their labor income less taxes:[9]

$$C_t^h = w_t H_t - T_t^h, \tag{11}$$

where their consumption is C_t^h, labor income is $w_t H_t$ (see below) and T_t^h are taxes that hand-to-mouth households have to pay. Overall taxes are given by a time-invariant component T^h and a countercyclical transfer scheme:[10]

$$T_t^h = \frac{\tau}{\lambda} \left(Y_t - Y\right) + T^h. \tag{12}$$

$\tau \geq 0$ captures the degree of countercyclical transfers which rebates income whenever aggregate output is different from steady state $(Y_t - Y)$ – see section

[9]Such a behavior can be rationalized for instance by myopic behavior, a lack of access to capital markets or ignorance of intertemporal trading opportunities. As pointed out by Galí et al. (2007), this is a rather extreme form of non-Ricardian behavior, which nevertheless capture the observed heterogeneity in consumption responses and income as found in the data.

[10]The time-invariant component ensures that in steady state consumption is similar across households (i.e. $C^h = C^o$, see also Galí et al., 2007).

2.5 for more details and how the optimizers pay for that transfer.[11] Although this transfer scheme is stylized, it captures in a parsimonious way automatic stabilizers that are found in more complex settings (see for instance Leeper, Plante and Traum, 2010).[12] Additionally, it seems the most direct way to introduce redistribution within the two heterogeneous agents.

2.2 Labor agencies

Each household supplies a specialized type of labor H_t^j, independent of whether it is a Ricardian or a rule-of-thumb household (in the spirit of Erceg, Henderson and Levin, 2000). Since firms do not differentiate between the two households when hiring labor for a specialized type j, the supply of hours and the wage rate is the same for both groups. The labor agencies bundle the specialized labor inputs into a homogeneous labor output that it sells to the intermediate good firm according to

$$H_t = \left[\int_0^1 \left(H_t^j\right)^{1/(1+\lambda_{w,t})} dj \right]^{1+\lambda_{w,t}} \tag{13}$$

where $\lambda_{w,t}$ is the wage mark-up, following (in linearized form)

$$\lambda_{w,t} = (1-\rho_{\lambda^w})\ln(\lambda_w) + \rho_{\lambda^w}(\lambda_{w,t-1}) + \epsilon_{\lambda_{w,t}}. \tag{14}$$

The demand for the different types of labor inputs is given by

$$H_t^j = \left(\frac{W_t^j}{W_t}\right)^{-\frac{1+\lambda_{w,t}}{\lambda_{w,t}}} H_t \tag{15}$$

In each period, the probability of resetting the wage is $(1-\theta_w)$, while with the complementary probability (θ_w) the wage is automatically increased following the indexation rule:

$$W_t^j = \Pi_{t-1}^{\iota_w} W_{t-1}^j$$

The maximization problem of a given union for the specialized labor input j is given by (similar to Colciago, 2011):

$$\max_{\tilde{W}_t} E_t \sum_{s=0}^{\infty} (\beta\theta_w)^s \left\{ (1-\lambda)\, u\left(C_{t+s}^o\right) + \lambda u\left(C_{t+s}^h\right) - d_{t+s}\Lambda_{t+s}^a B \frac{H_{t+s}^{1+\eta}}{1+\eta} \right\}$$

[11] Bilbiie (2019a) proposes to rebate firm profits. In our model not all kinds of profits would imply a taming of the impact of forward guidance. For instance, bank profits would amplify the aggregate effects because they are strongly procyclical (reduction of interest rates constitutes a capital gain for banks, raising profits). In contrast, intermediate good profits are countercyclical (similar to mark-ups after demand-type driven shocks).

[12] The study of more complex transfer rules or distortionary taxes seems interesting, but is beyond the scope of the paper.

s.t. the budget constraints (3), (11) and labor demand (15) and with $\Lambda^a_{t+s} = (1-\lambda)\Lambda^o_{t+s} + \lambda\Lambda^h_{t+s}$.[13]

2.3 Financial intermediaries

The financial intermediaries (FI) in the model use accumulated net worth N_t and short-term deposits D_t to finance investment bonds F_t and long-term government bonds B_t. Their balance sheet is given by:

$$\underbrace{Q_t\frac{B_t}{P_t}}_{\overline{B}_t} + \underbrace{Q_t\frac{F_t}{P_t}}_{\overline{F}_t} = N_t + \frac{D_t}{P_t} = L_t N_t, \tag{16}$$

where L_t denotes leverage. Note that investment and government bonds are perfect substitutes since they offer the same payment streams and thus are valued at the same price Q_t. Define the return on those bonds as R^L_t:

$$R^L_t \equiv \frac{1+\kappa Q_t}{Q_{t-1}}. \tag{17}$$

Every period a financial intermediary receives the coupon payment of 1 from its old assets in $t-1$, which it additionally sells completely. Its income is thus $(1+\kappa Q_t)\left(\frac{B_{t-1}}{P_t} + \frac{F_{t-1}}{P_t}\right)$. It purchases new assets at price Q_t, such that the real value of these purchases is $Q_t\left(\frac{F_t}{P_t} + \frac{B_t}{P_t}\right)$. It further collects new deposits D_t and has to pay out interest rate expenses on the deposits of the previous period $R^d_{t-1}\frac{D_{t-1}}{P_t}$. Any change in the net worth from steady state will be costly: $f(N_t)N_t$, with $f(N_t) = \frac{\Psi_n}{2}\left(\frac{N_t - N}{N}\right)^2$.[14] Thus, the remaining dividend payments are given by interest income less the expenditures:

$$div^{FI}_t = (1+\kappa Q_t)\left(\frac{B_{t-1}}{P_t} + \frac{F_{t-1}}{P_t}\right) + \frac{D_t}{P_t} - Q_t\left(\frac{F_t}{P_t} + \frac{B_t}{P_t}\right) - R^d_{t-1}\frac{D_{t-1}}{P_t} - f(N_t)N_t$$

$$\Leftrightarrow div^{FI}_t + (1+N_t)f(N_t) = \underbrace{\frac{P_{t-1}}{P_t}\left(\left(R^L_t - R^d_{t-1}\right)L_{t-1} + R^d_{t-1}\right)N_{t-1}}_{\text{profits}}, \tag{18}$$

where the definition of the return R^L_t and the banks' balance sheet (16) were substituted. This equation shows that profits will be partly paid out as dividends div^{FI}_t to the (Ricardian) households while the rest is retained as net worth

[13] We define $\Lambda^h_{t+s} = d_{t+s}\frac{1}{c^h_{t+s}}$, i.e. without habit. The simulation results do not change qualitatively if we also introduce habit there.

[14] As will be shown below, a leverage constraint (due to a "hold-up" problem) limits the ability of the FI to attract deposits and thus eliminates the arbitrage opportunity between long and short rates. However, this limit to arbitrage could be undone by an increase in net worth (implicitly, that would be a lump-sum transfer (tax) on the (Ricardian) households). The net worth adjustment cost ensure that this does not happen.

for subsequent activity. The FI discounts dividend flows using the (Ricardian) household's pricing kernel augmented with additional impatience $\zeta < 1$, which allows for a positive excess return of long-term debt over deposits in steady state.[15]

The FI then chooses dividends div_t^{FI} and net worth N_t to maximize expected dividend payments

$$V_t = E_t \sum_{s=0}^{\infty} (\beta\zeta)^s \Lambda_{t+s} div_{t+s}^{FI} \tag{19}$$

subject to (18). This yields the following first-order condition:

$$\Lambda_t \left[1 + f(N_t) + N_t f'(N_t)\right] = E_t \Lambda_{t+1} \beta\zeta \frac{P_t}{P_{t+1}} \left[\left(R_{t+1}^L - R_t^d\right) L_t + R_t^d\right]. \tag{20}$$

The FIs are subject to a simple hold-up problem which limits their ability to attract deposits (in spirit similar to Gertler and Karadi, 2013). We follow the approach by Carlstrom et al. (2017) completely and arrive at the following expression for the leverage constraint L_t:[16]

$$L_t = \frac{1}{\left[1 + (\Phi_t - 1) E_t \frac{R_{t+1}^L}{R_t^d}\right]}, \tag{21}$$

where Φ_t measures exogenous changes in the financial friction:

$$\Phi_t = (1 - \rho_\Phi)\, \Phi + \rho_\Phi \Phi_{t-1} + \varepsilon_{\Phi,t}. \tag{22}$$

2.4 Goods market

Perfectly competitive final goods producers combine differentiated intermediate goods $Y_t(i)$ into a homogeneous good Y_t according to the technology:

$$Y_t = \left[\int_0^1 Y_t(i)^{\frac{1}{1+\lambda_{p,t}}} di\right]^{1+\lambda_{p,t}}$$

where $\lambda_{p,t}$ is the time-varying price mark-up that evolves according to

$$\lambda_{p,t} = (1 - \rho_{\lambda_p}) \ln(\lambda_p) + \rho_{\lambda_p} \lambda_{p,t-1} + \varepsilon_{\lambda_{p,t}}. \tag{23}$$

Profit maximization leads to the following demand function:

$$Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\frac{1+\lambda_{w,t}}{\lambda_{w,t}}} Y_t, \tag{24}$$

[15] It can be shown that $R^L = R^d + \frac{1-\zeta}{\zeta L} R^d > R^d$ if $\zeta < 1$.

[16] Details of the derivation can be found in their paper.

with

$$P_t = \left[\int_0^1 P_t(i)^{-\frac{1}{\lambda_{w,t}}} di \right]^{-\lambda_{w,t}}. \tag{25}$$

A continuum of monopolistic competitive firms combines capital K_{t-1} and labor H_t to produce intermediate goods according to a standard Cobb-Douglas technology. The production function is given by:

$$Y_t(i) = A_t K_{t-1}(i)^{\alpha} H_t(i)^{1-\alpha} \tag{26}$$

with

$$A_t = (1-\rho_a)\ln(A) + \rho_a A_{t-1} + \epsilon_{A,t}. \tag{27}$$

The intermediate goods producers set prices based on Calvo contracts. In each period firms adjust their prices with probability $(1-\theta_p)$ independently form previous adjustments. Those firms that cannot adjust their prices in a given period will re-set their prices according to the following indexation rule:

$$P_t(i) = \Pi_{t-1}^{\iota_p} P_{t-1}(i).$$

Firms that can adjust their prices face the following problem:

$$\max_{P_t^*} E_t \sum_{s=0}^{\infty} \theta_p^s \frac{\beta^s \Lambda_{t+s}}{\Lambda_t} \left[\frac{P_t^* \left(\prod_{k=1}^{s} \Pi_{t+k-1}^{\iota_p} \right)}{P_{t+s}} Y_{t+s}(i) - \frac{W_{t+s}}{P_{t+s}} H_{t+s}(i) - R_{t+s}^k K_{t-1+s}(i) \right],$$

subject to labor demand (15) and $Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\varepsilon_{p,t}} Y_t$. It holds that dividends are given by $div_t^{IG} = Y_t - w_t H_t - R_t^k K_{t-1}$.

The capital goods producers take final output I_t and sell it (with a mark-up) subject to adjustment costs to the households, therefore dividends $div_t^{CP} = P_t^k I_t^n - I_t = P_t^k \mu_t \left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right] I_t - I_t$, where the investment specific technology shock follows an AR(1) process:

$$\mu_t = (1-\rho_\mu)\ln(\mu) + \rho_\mu \mu_{t-1} + \varepsilon_{\mu,t}. \tag{28}$$

The profit maximization is then described by

$$\max_{I_t} E_t \sum_{s=0}^{\infty} \beta^s \Lambda_{t+s} \left[P_{t+s}^k \mu_{t+s} \left[1 - S\left(\frac{I_{t+s}}{I_{t+s-1}} \right) \right] I_{t+s}) - I_{t+s} \right]. \tag{29}$$

2.5 Government policies

The central bank follows a Taylor rule when setting its short-term policy rate R_t:[17]

$$\ln(R_t) = (1-\rho)\ln(R) + \rho\ln(R_{t-1}) + (1-\rho)\left(\tau_\pi(\pi_t - \pi) + \tau_y(y_t - y_{t-1})\right) + R_t^\epsilon$$

with

$$R_t^\epsilon = (1-\rho_m)\ln(R^\epsilon) + \rho_m R_{t-1}^\epsilon + \varepsilon_{R,t}. \tag{30}$$

The government collects taxes T_t in a lump-sum fashion and issues government bonds $\frac{Q_t B_t}{P_t}$ to finance its outstanding debt including coupon payments $(1+\kappa Q_t)\frac{B_{t-1}}{P_t}$.[18] Its simple budget constraint is given by:

$$\frac{Q_t B_t}{P_t} + T_t = (1+\kappa Q_t)\frac{B_{t-1}}{P_t}. \tag{31}$$

Note that tax-income $T_t = \lambda T_t^h + (1-\lambda)T_t^o$ is net of the countercyclical transfers paid to hand-to-mouth households. Implicitly, there is redistribution of countercyclical transfers $\tau(Y_t - Y)$ from optimizing to hand-to-mouth households (via the government). The respective tax rules for both agents are given by the following two equations:

$$T_t^o = \frac{1}{1-\lambda}\left(T^t + T^o - \tau(Y_t - Y)\right) \tag{32}$$

$$T_t^h = T^h + \frac{\tau}{\lambda}(Y_t - Y). \tag{33}$$

For simplicity, only the Ricardian households finance the government. Additionally, they are involved in the countercyclical transfer system in which the hand-to-mouth households participate as well. The degree of countercyclicality is given by τ. T^o and T^h are chosen such that consumption of hand-to-mouth households and Ricardian households coincide in steady state.[19]

2.6 Aggregation

Taking the household and the government budget constraint, as well as all dividend payments, one arrives at the aggregate resource constraint

$$Y_t = C_t + I_t + f(N_t)N_t, \tag{34}$$

[17]Since short-term government debt and bank deposits are perfect substitutes it holds that $R_t^d = R_t$.

[18]Since debt-stabilizing taxes are levied on Ricardian households only, there is no feedback of debt-dynamics on decisions due to Ricardian equivalence. However, this does not apply to the redistribution scheme.

[19]As the focus of this paper is on the effect of forward guidance when a fraction of households does not feature forward-looking behavior – and not so much about different consumption distributions – we view that assumption as being largely justifiable.

where aggregate consumption and investment are given by a weighted average of the respective variables for optimizer and rule-of-thumb households:

$$C_t = (1 - \lambda)\, C_t^o + \lambda C_t^h \tag{35}$$

and

$$I_t = (1 - \lambda)\, I_t^o. \tag{36}$$

Similarly, the aggregate capital stock is given by

$$K_t = (1 - \lambda)\, K_t^o. \tag{37}$$

3 Estimation

After linearizing the model around the steady state we estimate it using Bayesian estimation methods. We use eight quarterly euro area time series with the sample period 1999Q1 to 2014Q4.[20] In this section, we first describe the dataset, followed by description of the calibration and prior distributions of the respective parameters. Finally, we report the corresponding posterior distributions.

3.1 Data

We use a total of eight observables for the euro area: real GDP per capita, real investment, gross inflation, employment growth, real wage growth, the first difference of the short- and long-term interest rate, and real bank net worth growth. The time series on bank net worth is taken from the European Central Bank's MFI Balance Sheet Items Statistics. All the other variables are taken from the Area-wide Model database of the ECB.[21] Since we have only seven structural shocks in the model, we add a measurement error to the observations equation for bank net worth in order to avoid stochastic singularity.

Per capita output and investment are obtained by dividing real GDP (YER) and investment (ITR) by the number in the labor force (LFN). Growth rates are log-differences. Inflation is measured as the growth rate of the seasonally adjusted Harmonised Index of Consumer Prices (HICPSA). Employment growth is the log-difference of the total employment (LNN). For the real wage series we first divide the nominal wage rate per head (WRN) by the HICPSA and then take the log-difference. Our short-term nominal interest rate is the 3-month Euribor rate (STN) and our long-term nominal interest rate the euro area 10-year government benchmark bond yield (LTN). Real bank net worth is obtained by dividing the

[20]We stopped the estimation before interest rates (especially the 3-month Euribor) turned negative in 2015Q2 in our sample.

[21]We use the 18th update of the Area-wide Model (AWM) database from August 2018.

nominal capital and reserves of euro area monetary financial institutions (excluding eurosystem) (NWB) by HICPSA and taking the log-difference. All series are demeaned with their respective sample mean.[22]

$$\begin{bmatrix} \text{dlGDP}_t \\ \text{dlInvestment}_t \\ \text{dlGDPDeflator}_t \\ \text{ShortInterestRate}_t \\ \text{LongInterestRate}_t \\ \text{dlHours}_t \\ \text{dlWages}_t \\ \text{dlNetworth}_t \end{bmatrix} = 100 \cdot \begin{bmatrix} 0 \\ 0 \\ \log(\Pi) \\ \log(\Pi/\beta) \\ \log(\Pi/\beta) + 0.01/4 \\ 0 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} \hat{y}_t - \hat{y}_{t-1} \\ \hat{x}_t - \hat{x}_{t-1} \\ \hat{\pi}_t \\ \hat{r}_t \\ \hat{r}_t^{L,10} \\ \hat{h}_t - \hat{h}_{t-1} \\ \hat{w}_t - \hat{w}_{t-1} \\ \hat{n}_t - \hat{n}_{t-1} + \varepsilon_{n,t} \end{bmatrix},$$

We match the long-term interest rate time series to the yield-to-maturity of the 10 year government bond $\hat{r}_t^{L,10} = \log R_t^{L,10} - \log R^{L,10}$, with $R_t^{L,10} = \frac{1}{Q_t} + \kappa$ (see Carlstrom et al., 2017).

3.2 Calibration and prior distributions

As is common in the literature, we calibrate a subset of the structural parameters to ensure identification. We follow mostly the calibration of Carlstrom et al. (2017).[23] The time preference β is set to 0.99, yielding a steady state annual real interest rate of roughly 4%. The labor income share α is set to 0.33 and the depreciation rate to $\delta = 0.025$, which implies a 10% annual depreciation of the capital stock. The steady state mark-ups of prices and wages are set to 20%, i.e. $\lambda_w = \lambda_p = 0.2$. The leverage ratio is set to 6 which implies $\zeta = 0.9854$. We impose that in steady state the annual long-term rate R^L is one percentage point above the short-term one, i.e. $R^L = R^{L,10} = R + 0.01/4$ (see the observation equation).[24] In order to estimate the model with a 10-year government bond (similar to its empirical counterpart) we set $\kappa = 0.975$. It was not possible to identify the share of hand-to-mouth households λ and the redistribution coefficient τ simultaneously in the data. We therefore calibrate the share of constrained households to 30% since there is empirical evidence for such a share (e.g. Dolls, Fuest and Peichl, 2012; Bilbiie and Straub, 2013; Fève and Sahuc, 2017).[25] The prior choices are largely taken from Carlstrom et al. (2017) and are summarized in columns 2 to 4 of Table 1. The first block of parameters determine

[22] An estimation of the steady states (for instance inflation) did not change the results much.

[23] We cross-check with values from Smets and Wouters (2003) which studied the euro area, but the results were largely unchanged.

[24] In the data the long-term rate for the sample period was roughly 1.5pp higher than the short-term rate. However, results were basically unchanged when we estimated the model with this higher value.

[25] As a cross check we estimated the model with the calibrated redistribution τ (at the posterior mean of Table 1) and found a share of hand-to-mouth households of around 0.35.

Table 1: Prior and posterior distribution of estimated parameters

		Prior			Posterior			
		Dist	Mean	SE	Mode	Mean	5 percent	95 percent
Utility & technology								
h	Habit	B	0.5	0.2	0.7721	0.7759	0.7120	0.8443
η	Inverse Frisch	G	2	0.5	1.7190	1.8942	1.1331	2.6954
ψ_I	Investment adj.costs	G	10	1.0	14.097	14.188	12.306	15.996
ψ_N	Net worth adj. costs	G	3	1.0	5.8016	6.2013	4.3656	7.9765
Stickiness								
ι_p	Price indexation	B	0.6	0.1	0.4979	0.5264	0.3584	0.6925
ι_w	Wage indexation	B	0.6	0.1	0.3079	0.3341	0.2192	0.4385
θ_p	Price stickiness	B	0.7	0.1	0.8046	0.8138	0.7620	0.8712
θ_w	Wage stickiness	B	0.7	0.1	0.8557	0.8557	0.8139	0.8983
Government policy								
ρ	MP smoothing	B	0.7	0.1	0.7242	0.7274	0.6741	0.7828
τ_π	MP on inflation	N	1.5	0.1	1.5508	1.5868	1.4453	1.7382
τ_y	MP on output	N	0.5	0.1	0.5723	0.5811	0.4313	0.7292
τ	Size redistribution	B	0.1	0.15	0.1571	0.1457	0.0683	0.2245
AR(1) shocks								
ρ_a	TFP	B	0.60	0.20	0.9876	0.9842	0.9710	0.9985
ρ_ϕ	Financial friction	B	0.60	0.20	0.7398	0.7233	0.6600	0.7851
ρ_μ	Investment specific	B	0.60	0.20	0.8787	0.8688	0.8196	0.9183
ρ_{λ_w}	Wage markup	B	0.60	0.20	0.1803	0.2195	0.0537	0.3704
ρ_{λ_p}	Price markup	B	0.60	0.20	0.4906	0.4471	0.2408	0.6598
ρ_d	Demand	B	0.60	0.20	0.4710	0.4901	0.3060	0.6848
ρ_m	Monetary policy	B	0.60	0.20	0.5081	0.4929	0.3579	0.6337
Std shocks								
σ_a	TFP	IG	0.50	1.00	0.0057	0.0059	0.0050	0.0067
σ_ϕ	Financial friction	IG	0.50	1.00	0.1844	0.1984	0.1518	0.2436
σ_μ	Investment specific	IG	0.50	1.00	0.0982	0.1011	0.0834	0.1193
σ_{λ_w}	Wage markup	IG	0.10	1.00	0.8051	0.9759	0.3414	1.6889
σ_{λ_p}	Price markup	IG	0.10	1.00	0.0466	0.0608	0.0251	0.1000
σ_d	Demand	IG	0.10	1.00	0.6141	0.0313	0.0210	0.0408
σ_r	Monetary policy	IG	0.10	1.00	0.0283	0.0032	0.0027	0.0037
σ_N^{ME}	ME on net worth	IG	0.001	1.00	0.0117	0.0120	0.0103	0.0138

Notes: N stands for the Normal, B the Beta, G the Gamma and IG the inverted Gamma distribution.

the shape of the utility and cost functions. For the amount of habit h, we use a beta distribution with mean 0.5 and standard deviation of 0.2. The inverse Frisch elasticity η has a relatively flat prior centered around 2. The prior mean and standard deviation for the investment adjustment costs Ψ_I are taken from the posterior mode of Coenen, Karadi, Schmidt and Warne (2018).
For the amount of indexation and the amount of stickiness we use a beta distribution centered around 0.6 and 0.7, respectively, with a standard deviation of 0.1 for all four parameters.
The prior of the degree of monetary persistence is a beta distribution with mean 0.7 and standard deviation of 0.1. The two Taylor coefficients on inflation and output follow both a normal distribution centered around 1.5 and 0.5 respectively. For the size of redistribution we took a relatively flat prior around 0.3 (the share of hand-to-mouth households).
We specify for all autocorrelations of the shocks a beta distribution which is centered around 0.6 with a standard deviation of 0.2.[26] All priors for the standard deviations of shocks follow a relatively flat inverse gamma distribution with standard deviation of 1. The prior of the wage markup, price markup, demand and monetary policy are all centered around 0.1. For TFP, financial friction and the investment specific technology we use slightly higher values of 0.5. The mean for the measurement error on net worth is taken from the variance of the underlying data sample.

3.3 Posterior distribution

With the above specified prior distributions, we draw from the posterior distributions using the Metropolis-Hastings algorithm with two chains, each with 1,000,000 draws. In order to assess the convergence of the chains, we compute several measures following (Brooks and Gelman, 1998). The interval of the posterior distribution which is covered by the chains, as well as the second moment of the posterior distribution, seem to be stable for most parameters after approximately 500,000 draws. We report results based on the last 100,000 draws of each chain.
The last columns of Table 1 report the posterior mode, the posterior mean, and the lower and upper bounds of the 90% posterior density interval of the estimated parameters obtained by the Metropolis-Hastings algorithm. Most of our estimates are largely in line with similar estimates for the euro area (e.g. Smets and Wouters, 2003; Coenen et al., 2018). In the Appendix we plot the prior and the posterior distribution of each parameter.
Compared to the above two studies, we find for our data a slightly higher value of habit and wage stickiness and much lower persistence of monetary policy (around 0.72 compared to above 0.9 in the other two studies). However, note that the monetary policy shock is also persistent, therefore our parameters actually imply

[26]Note that for better identification of the autocorrelation of the monetary policy shock and the persistence in the Taylor rule we use a slightly tighter prior on the persistence, see above.

a more persistent monetary policy response for a monetary policy shock. Additionally, our quantitative simulations below do not change qualitatively if we assume a higher monetary policy persistence. We estimate the degree of redistribution $\tau \sim 0.15$[27]. This is relatively close to Leeper et al. (2010), who find τ in the range 0.05 to 0.25 with a mean of 0.13 in a similar transfer rule for a representative agent model.
For robustness, we estimated the model from 1999 to 2007 to check that the estimates are not distorted by the financial crisis. Overall the parameters are not that different and are within the posterior bands: there is in general less persistence in the system (smaller AR(1) coefficients) and smaller nominal rigidities (although the indexation parameter is high in either case). The redistribution parameter τ is smaller (0.143 instead of 0.157). For a second robustness check, we estimated the model from 1999 to 2014 with consumption instead of GDP as observable. Again, the estimated parameters are not that different. A notable exception is the size of redistribution, τ, which is reduced to 0.117. However, even this smaller value for redistribution implies a reduction compared to the representative version, as the next section makes clear (specifically, Figure 3).

4 Simulations

In order to assess the quantitative implications of hand-to-mouth consumers we run several forward guidance simulations using the anticipated news approach of Laséen and Svensson (2011). We start with the impact forward guidance, implemented as an interest rate peg of 25bps annually below steady state for six quarters. This scenario is (as of June 2019) in essence similar to a cut in the deposit facility rate of 25bps with an extension of forward guidance "until the end of 2020". According to recent estimates of EONIA forward curves, this seems to be a plausible scenario for the euro area, see Lane (2019). We compare this scenario within three models: 'TANK + transfers' (blue dotted line, i.e. our estimated two-agent New Keynesian (TANK) model specified in section 2), 'TANK' (red solid-dotted line, no transfers, i.e. $\tau = 0$) and 'RANK' (black solid line, the Representative Agent New Keynesian (RANK) model with no hand-to-mouth households, i.e. $\tau = \lambda = 0$).

Figure 1 illustrates how such an expansionary forward guidance (upper left panel) lowers long-term interest rates (upper middle panel) and thus stimulates investment (upper right panel) and consumption (bottom left panel). This raises real GDP (bottom middle panel) and inflation (bottom right panel). As one can see, both TANK variants encompass the RANK model: the impact of forward guidance is more pronounced in the TANK model (hence, the above mentioned

[27] This is in principle the same number as in Gerke, Giesen and Scheer (2020). However, in that paper τ^{GGS20} is around 0.5 with the transfer rule $T_t^h = \tau^{GGS20} (Y_t - Y) + T^h$. Here, we use the transfer rule $T_t^h = \frac{\tau}{\lambda} (Y_t - Y) + T^h$. Hence our value of τ is simply a scaled version from Gerke et al. (2020), as the following holds: $\tau^{GGS20} = \frac{\tau}{\lambda}$.

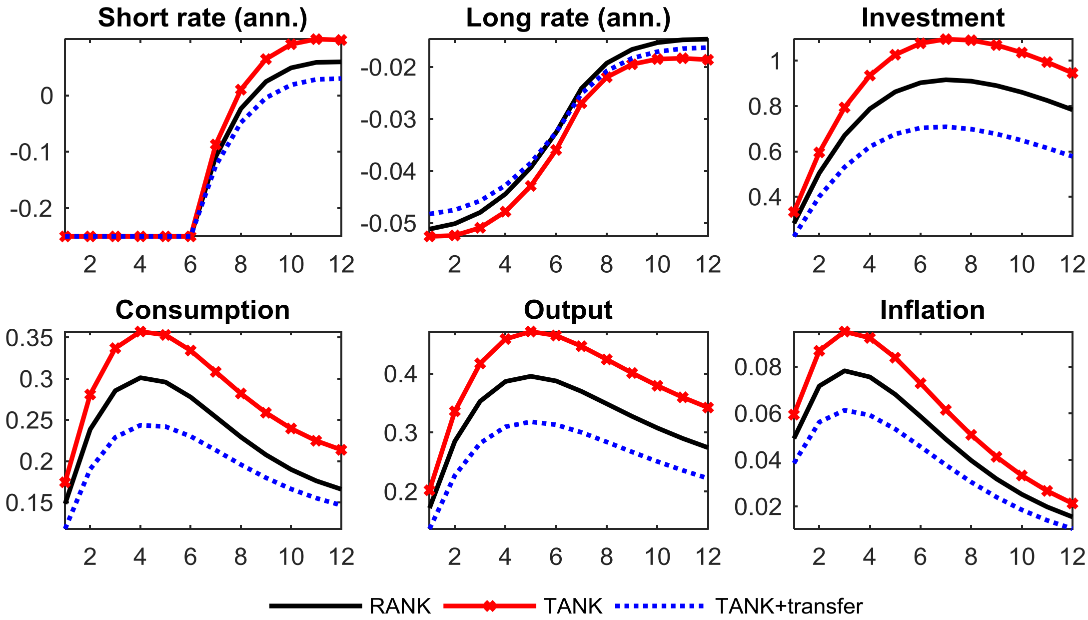

Figure 1: Simulated quarterly responses of aggregates in %-deviation from steady state, if the interest rate is held 25bps annually below steady state for six quarters.

indirect effect dominates as in Bilbiie, 2019b) but less pronounced in our TANK model with transfers (the direct effect dominates).

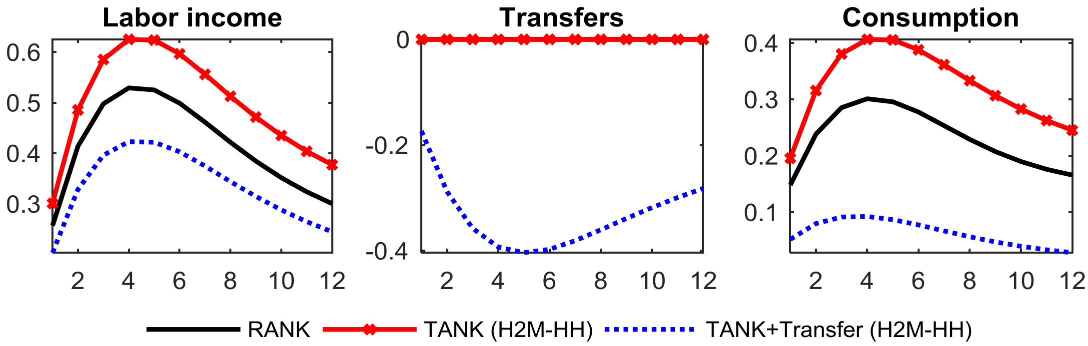

Figure 2: Simulated quarterly responses for an interest rate peg of 25bps below steady state for six quarters in %-deviation from steady state. It depicts aggregate variables for RANK and the response of hand-to-mouth households on TANK (red solid-dotted line) and Tank with transfers (blue dotted line) over time (quarters).

The amplified (dampened) aggregate response can be explained if we examine the strength of the indirect effect, i.e. by inspecting the constrained households' total income and their consumption demand. Figure 2 depicts the response of labor income, transfers and consumption only for the *constrained* households (for both TANK models) and contrasts them to (the aggregate response in) RANK.

Focus on TANK first (no transfers, red solid-dotted line). The left panel reveals

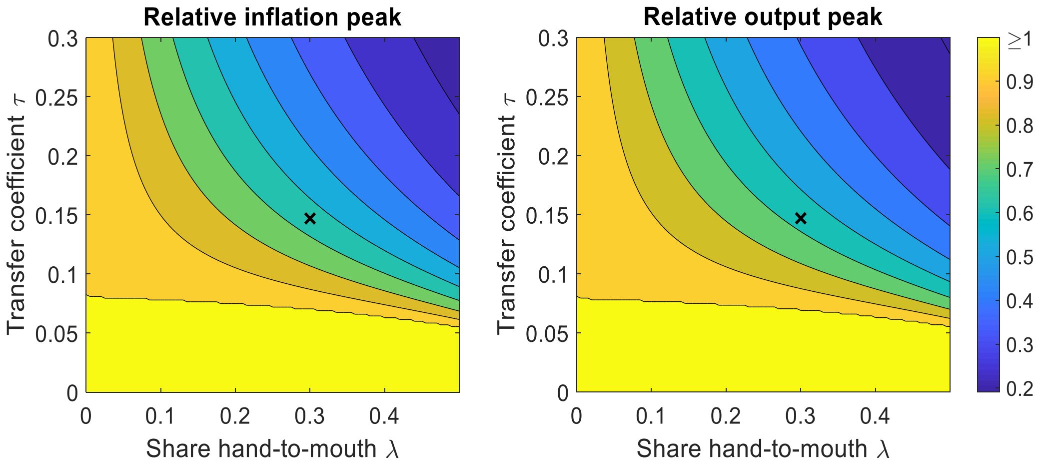

Figure 3: Peak response of inflation (left panel) and output (right panel) for different parameterized TANK models relative to our RANK model for eight quarters of forward guidance. Values above 1 indicate an amplification (all in bright yellow), values below 1 a dampening. The cross denotes estimated values.

that labor (and thus total) income of hand-to-mouth households increases compared to RANK, which raises their consumption demand (right panel) and thus aggregate consumption, investment and income (red solid-dotted line in Figure 1). Therefore, although a smaller fraction of households smooths intertemporally (which should per se dampen the aggregate effects of forward guidance), the higher marginal propensity to consume of constrained households predominates. Now, contrast these dynamics with the empirical TANK that includes countercyclical transfers (blue dotted line). As the expansionary policy leads to a boom, hand-to-mouth households receive less countercyclical transfers (middle panel), so they reduce (relatively) their consumption demand (right panel). This feeds back into a relatively smaller aggregate response and thus lower wage income (left panel). The (relative) fall in labor income and transfers results in a relatively small consumption response of hand-to-mouth households, which dampens the impact on aggregate consumption (bottom left panel in Figure 1). Hence, the direct effect outweighs the indirect one and the power of forward guidance is attenuated.

To assess the contribution of the share of hand-to-mouth households λ and the associated degree of countercyclical redistribution τ that is necessary to reduce the power of forward guidance, Figure 3 contrasts the relative peak response of inflation (left panel) and output (right panel) for eight quarters of forward guidance with different combinations of λ and τ. A value above 1 (depicted in bright yellow) indicates an amplification and a value below 1 a dampening relative to RANK.

There are two takeaways. First, there is a non-negligible parameter region where the introduction of hand-to-mouth households amplifies the effects of forward guidance, especially when redistribution is low. Second, the combination of a high share of constrained households and significant redistribution leads to the strongest reduction of the power of forward guidance. The crosses in the figure highlight the values that were used for Figure 1 and 2. For this parameter combination, the power of forward guidance is reduced by approximately 40% compared to our RANK benchmark.[28] However, the amount of attenuation depends on the length of forward guidance. In case the central bank promises an expansionary stance for only 6 quarters, the peak impact of inflation is reduced by approximately 22%.

Although our TANK model with transfers can thus attenuate the power of forward guidance, it does *not resolve* the so-called forward guidance puzzle (Del Negro et al., 2015), see Figure 4. This figure depicts for all three model variants ('RANK', 'TANK', 'TANK+transfer') an exponentially increasing peak impact of three consecutive rate cuts on consumption (left panel), inflation (middle panel) and output (right panel), at different horizons at which these cuts occur. As one can see, even though the peak impact is reduced in the estimated TANK model with transfers (blue dotted line) compared to the pure TANK model (red solid-dotted line), the impact is still increasing the further away the cuts occur. Hence, to actually resolve the puzzle in our model, one would probably have to add uninsurable idiosyncratic income risk to the model (as in a HANK model), that triggers a yet missing self-insurance mechanism (as shown for a simple TANK analytically by Bilbiie, 2019a).

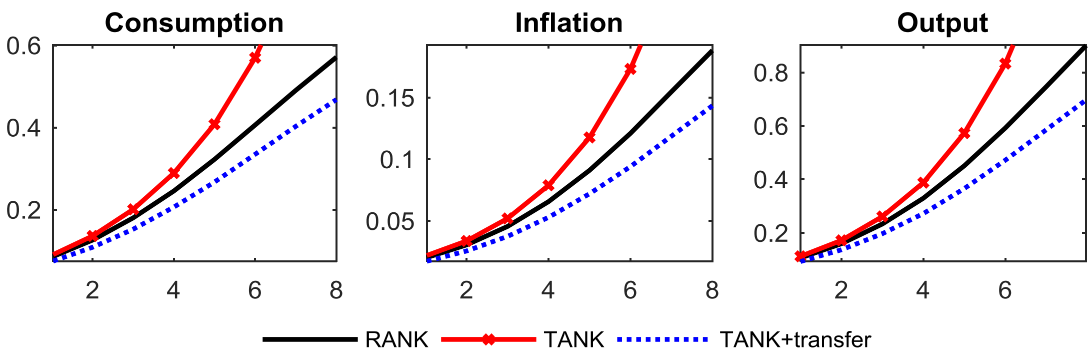

Figure 4: Simulated peak responses for different horizons of forward guidance on three consecutive rate cuts of 25bps. The horizontal axis depicts the respective horizon when the cuts occur, the vertical one the impact in % relative to steady state.

In a last scenario we illustrate the interaction of forward guidance (FG) with asset purchases (APP), as observed in recent years. As a baseline, we simulate the impact of the Eurosystem's asset purchase program as of early 2015 (similar to Sahuc, 2016), within our estimated TANK model with transfers (blue solid line in Figure 5). The purchases (upper left panel) stimulate investment through portfolio-rebalancing (not shown), which raises real GDP (not shown) and in-

[28]In McKay et al. (2016) the HANK model reduces the initial impact of their forward guidance experiment by 60% compared to their RANK model.

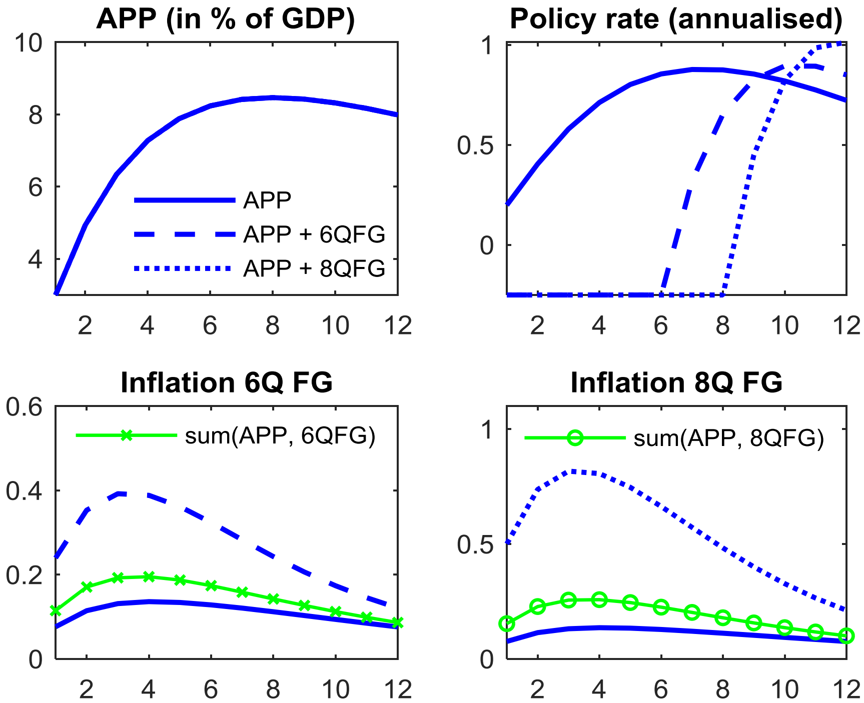

Figure 5: Simulated response of APP and APP with FG (interest rate set 25bps below the steady state for six and eight quarters). The horizontal axis depicts quarters, the vertical one the impact in % relative to steady state. The blue solid line depicts the response of the APP-baseline scenario, the blue dashed (blue dotted) line the interaction with six (eight) quarters FG. The green solid-cross and solid-circle lines depict the sum of the APP-baseline and an isolated FG impact of a 25bps cut for six and eight quarters, respectively.

flation (bottom left and right panel). As a result, the policy rate also increases (upper right panel).

We compare these responses with a scenario where we additionally keep the interest rate 25bps annually below steady state for six quarters (blue dashed line) and eight quarters (blue dotted line). In both cases, as expected, the simultaneous use of APP and FG raises GDP (not shown) and inflation (bottom left and right panel, respectively) above the baseline scenario. However, it is noteworthy that the impact is higher than the sum of each policy used in isolation (the green solid-cross line for six quarters FG and the solid-circle line for eight quarters, respectively). The reason is twofold. First, monetary policy is more accommodative as it lowers interest rates by more than 25bps (APP per se raises policy rates). Second, this additional stimulus becomes reinforced due to the interest rate peg, as the rise of the inflation rate induces a further reduction in real interest rates, which amplifies the stimulus. This second amplification channel explains why the difference between the interaction and the sum of the isolated policies increases with the horizon of forward guidance (i.e. the difference between 'APP + 8QFG' and 'sum(APP, 8QFG)' is higher than between 'APP +

6QFG' and 'sum(APP, 6QFG)').[29]

5 Conclusion and discussion

We have introduced hand-to-mouth households into a medium-scale New Keynesian DSGE model with banks to study the quantitative implications of forward guidance. We also study its combination with asset purchases. Such a two-agent New Keynesian model approximates the aggregate effects of heterogeneous agents models in a parsimonious way. We show that for plausible ranges of parameters the power of forward guidance can be dampened compared to our representative agent benchmark model. However, the amount of attenuation depends on the degree of countercyclical transfers and the share of hand-to-mouth households. This is because the two parameters shape the relative strength of the direct and indirect effects of interest rate forward guidance (Bilbiie, 2019b). If there is no or "too little" redistribution, models with hand-to-mouth households *amplify* the impact of forward guidance on the economy relative to a representative agent benchmark.

A further taming is possible if monetary policy is history dependent. An inertial reaction of the central bank will carry its endogenous feedback of interest rates into the future after the forward guidance period (similar to Bilbiie, 2019a). As many central banks indeed emphasize a medium-term goal of their inflation targets, we estimated a version of the above model with a Taylor rule that reacts to a four-quarter average of the past inflation rates (e.g. Justiniano, Primiceri and Tambalotti, 2013). Our results indeed indicate a further taming of the power of forward guidance. However, the forward guidance puzzle remains unsolved. We leave a thorough analysis of the quantitative implications of different monetary policy rules and strategies for future work.

References

Acharya, S. and Dogra, K. (2019). Understanding HANK: Insights from a PRANK.

Angeletos, G.-M. and Lian, C. (2018). Forward Guidance without Common Knowledge, *American Economic Review* **108**(9): 2477–2512.

[29] The isolated impact of the APP on inflation is around 0.14%. The isolated impact of a 25bps reduction in the short rate for six / eight quarters is around 0.06% / 0.12%, respectively. However, the combination of APP and forward guidance raises inflation by 0.39% and 0.82%, respectively.

Bilbiie, F. O. (2008). Limited Asset Markets Participation, Monetary Policy and (Inverted) Keynesian Logic, *Journal of Economic Theory* **140**(1): 162–196.

Bilbiie, F. O. (2019a). Monetary Policy and Heterogeneity: An Analytical Framework.

Bilbiie, F. O. (2019b). The New Keynesian Cross, *Journal of Monetary Economics* (in press).

Bilbiie, F. O. and Straub, R. (2013). Asset Market Participation, Monetary Policy Rules, and the Great Inflation, *Review of Economics and Statistics* **95**(2): 377–392.

Brooks, S. P. B. and Gelman, A. G. (1998). General methods for monitoring convergence of iterative simulations, *Journal of computational and graphical statistics* **7**(4): 434–455.

Carlstrom, C. T., Fuerst, T. S. and Paustian, M. (2017). Targeting Long Rates in a Model with Segmented Markets, *American Economic Journal: Macroeconomics* **9**(1): 205–42.

Coenen, G., Karadi, P., Schmidt, S. and Warne, A. (2018). The New Area-Wide Model II: An Extended Version of the ECB's Micro-Founded Model for Forecasting and Policy Analysis with a Financial Sector.

Colciago, A. (2011). Rule-of-Thumb Consumers Meet Sticky Wages, *Journal of Money, Credit and Banking* **43**(2-3): 325–353.

Debortoli, D. and Galí, J. (2018). Monetary policy with heterogeneous agents: Insights from TANK models.

Del Negro, M., Giannoni, M. and Patterson, C. (2015). The Forward Guidance Puzzle.

Deutsche Bundesbank (2013). Monetary policy and banking business, *Monthly Report (August)* pp. 29–45.

Dolls, M., Fuest, C. and Peichl, A. (2012). Automatic stabilizers and economic crisis: US vs. Europe, *Journal of Public Economics* **96**(3-4): 279–294.

Erceg, C. J., Henderson, D. W. and Levin, A. T. (2000). Optimal monetary policy with staggered wage and price contracts, *Journal of monetary Economics* **46**(2): 281–313.

Fed (2008). *Press Release*, FOMC, Board of Governors of the Federal Reserve System, December 16th, 2008.

Fève, P. and Sahuc, J.-G. (2017). In search of the transmission mechanism of fiscal policy in the euro area, *Journal of Applied Econometrics* **32**(3): 704–718.

Gabaix, X. (2018). A Behavioral New Keynesian Model.

Galí, J., López-Salido, J. D. and Vallés, J. (2007). Understanding the Effects of Government Spending on Consumption, *Journal of the European Economic Association* **5**(1): 227–270.

García-Schmidt, M. and Woodford, M. (2019). Are Low Interest Rates Deflationary? A Paradox of Perfect-Foresight Analysis, *American Economic Review* **109**(1): 86–120.

Gerke, R., Giesen, S. and Scheer, A. (2020). The power of forward guidance in a quantitative TANK model, *Economics Letters* **186**.

Gertler, M. and Karadi, P. (2013). QE 1 vs. 2 vs. 3. . . : A Framework for Analyzing Large-Scale Asset Purchases as a Monetary Policy Tool, *International Journal of Central Banking* **9**(1): 5–53.

Harrison, R. (2015). Estimating the effects of forward guidance in rational expectations models, *European Economic Review* **79**: 196–213.

Justiniano, A., Primiceri, G. E. and Tambalotti, A. (2013). Is there a Trade-Off between Inflation and Output Stabilization?, *American Economic Journal: Macroeconomics* **5**(2): 1–31.

Kaplan, G., Moll, B. and Violante, G. L. (2018). Monetary policy according to HANK, *American Economic Review* **108**(3): 697–743.

Kiley, M. T. (2016). Policy paradoxes in the New Keynesian model, *Review of Economic Dynamics* **21**: 1–15.

Krause, M. U. and Moyen, S. (2016). Public Debt and Changing Inflation Targets, *American Economic Journal: Macroeconomics* **8**(4): 142–76.

Lane, P. R. (2019). *Monetary Policy and Below-Target Inflation*, July 2nd, 2019.

Laséen, S. and Svensson, L. (2011). Anticipated Alternative Policy Rate Paths in Policy Simulations, *International Journal of Central Banking* **7**(3): 1–35.

Leeper, E. M., Plante, M. and Traum, N. (2010). Dynamics of fiscal financing in the United States, *Journal of Econometrics* **156**(2): 304–321.

Luetticke, R. (2019). Transmission of Monetary Policy with Heterogeneity in Household Portfolios.

McKay, A., Nakamura, E. and Steinsson, J. (2016). The Power of Forward Guidance Revisited, *American Economic Review* **106**(10): 3133–58.

McKay, A., Nakamura, E. and Steinsson, J. (2017). The Discounted Euler Equation: A Note, *Economica* **84**(336): 820–831.

McKay, A. and Reis, R. (2016). The Role of Automatic Stabilizers in the U.S. Business Cycle, *Econometrica* **84**(1): 141–194.

Sahuc, J.-G. (2016). The ECB's asset purchase programme: A model-based evaluation, *Economics letters* **145**: 136–140.

Smets, F. and Wouters, R. (2003). An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area, *Journal of the European Economic Association* **1**(5): 1123–1175.

Werning, I. (2015). Incomplete Markets and Aggregate Demand.

Woodford, M. (2001). Fiscal Requirements for Price Stability, *Journal of Money, Credit & Banking (Ohio State University Press)* **33**(3).

A Model overview

$$\Lambda_t^o = d_t \frac{1}{C_t^o - hC_{t-1}^o} - E_t d_{t+1} \frac{h\beta}{C_{t+1}^o - hC_t^o} \tag{38}$$

$$\Lambda_t^o = \beta \Lambda_{t+1}^o \frac{R_t}{\Pi_{t+1}} \tag{39}$$

$$(w_t^*)^{1+\varepsilon_w \eta} = \frac{\varepsilon_w}{\varepsilon_w - 1} \frac{G_t^I}{G_t^{II}} \tag{40}$$

$$G_t^I = \lambda_{w,t} d_t B w^{\varepsilon_w (1+\eta)} H_t^{1+\eta} + \theta_w \beta E_t \left(\frac{\Pi_{t+1}}{\Pi_t^{\iota_w}} \right)^{(1+\eta)\varepsilon_w} G_{t+1}^I \tag{41}$$

$$G_t^{II} = \Lambda_t w^{\varepsilon_w} H_t + \theta_w \beta \left(\frac{\Pi_{t+1}}{\Pi_t^{\iota_w}} \right)^{\varepsilon_w - 1} G_{t+1}^{II} \tag{42}$$

$$w_t^{1-\varepsilon_w} = (1 - \theta_w) (w_t^*)^{1-\varepsilon_w} + \theta_w \left(\Pi_{t-1}^{\iota_w} \frac{w_{t-1}}{\Pi_{t-1}} \right)^{1-\varepsilon_w} \tag{43}$$

$$\Lambda^o P_t^k M = \beta \Lambda_{t+1}^o \left(R_{t+1}^k + (1 - \delta) P_{t+1}^k M_{t+1} \right) \tag{44}$$

$$\Lambda_t^o Q_t M_t = \beta \Lambda_{t+1}^o \left(\frac{(1 + \kappa Q_{t+1}) M_{t+1}}{\Pi_{t+1}} \right) \tag{45}$$

$$V_t^h = d_t \left(\log \left(C_t^o - hC_{t-1}^o \right) - d_t^w B \frac{H_t^{1+\eta}}{1 + \eta} \right) + \beta V_{t+1}^h \tag{46}$$

$$R_t^k = mc_t MPK_t \tag{47}$$

$$w_t = mc_t MPL_t \tag{48}$$

$$\Pi_t^* = \frac{\varepsilon_p}{\varepsilon_p - 1} \frac{X_t^I}{X_t^{II}} \Pi_t \tag{49}$$

$$X_t^I = Y_t \lambda_{p,t} mc_t + \theta_p \beta \frac{\Lambda_{t+1}^o}{\Lambda_t^o} \Pi_t^{-\iota_p \varepsilon_p} \Pi_{t+1}^{\varepsilon_p} X_{t+1}^I \tag{50}$$

$$X_t^{II} = Y_t + \theta_p \beta \frac{\Lambda_{t+1}^o}{\Lambda_t^o} \Pi_t^{\iota_p (1-\varepsilon_p)} \Pi_{t+1}^{\varepsilon_p - 1} X_{t+1}^{II} \tag{51}$$

$$\Pi_t^{1-\varepsilon_p} = (1-\theta_p) \left(\Pi_t^*\right)^{1-\varepsilon_p} + \theta_p \Pi_{t-1}^{\iota_p (1-\varepsilon_p)} \tag{52}$$

$$d_t^\pi = \Pi_t^{\varepsilon_p} \left((1-\theta_p) \left(\Pi_t^*\right)^{-\varepsilon_p} + \theta_p \Pi_{t-1}^{-\varepsilon_p \iota_p} d_{t-1}^\pi \right) \tag{53}$$

$$d_t^w = \theta_w \Pi_{t-1}^{-\iota_w \varepsilon_w} \left(\frac{w_t}{w_{t-1}} \Pi_t \right)^{\varepsilon_w} d_{t-1}^w + (1-\theta_w)^{\frac{1}{1-\varepsilon_w}} \left(1 - \theta_w \left(\Pi_{t-1}^{\iota_w} \frac{w_{t-1}}{w_t \Pi_t} \right)^{1-\varepsilon_w} \right)^{\frac{\varepsilon_w}{\varepsilon_w - 1}} \tag{54}$$

$$Y_t = C_t + I_t + f(N_t) N_t \tag{55}$$

$$d_t^\pi Y_t = A_t K_{t-1}^\alpha H_t^{1-\alpha} \tag{56}$$

$$K_t^o = (1-\delta) K_{t-1}^o + \mu_t \left(1 - \frac{\Psi_I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right) I_t^o \tag{57}$$

$$P_t^k \mu_t \left\{ 1 - S\left(\frac{I_t}{I_{t-1}} \right) - S'\left(\frac{I_t}{I_{t-1}} \right) \frac{I_t}{I_{t-1}} \right\} = 1 - \beta P_{t+1}^k \frac{\Lambda_{t+1}}{\Lambda_t} \mu_{t+1} \left\{ -S'\left(\frac{I_{t+1}}{I_t} \right) \left(\frac{I_{t+1}}{I_t} \right)^2 \right\} \tag{58}$$

$$\bar{B}_t + \bar{F}_t = N_t L_t \tag{59}$$

$$L_t = \frac{1}{1 + (\Phi_t - 1) E_t \frac{R_{t+1}^L}{R_t}} \tag{60}$$

$$P_t^k I_t^o = \bar{F}_t - \kappa \frac{\bar{F}_{t-1}}{\Pi_t} \frac{Q_t}{Q_{t-1}} \tag{61}$$

$$\Lambda_t^o \left(1 + N_t \left(\Psi_n \frac{N_t - N}{N}\right) + \frac{\psi_N}{2} \left(\frac{N_t - N}{N}\right)^2\right) = \beta \zeta \Lambda_{t+1}^o \frac{1}{\Pi_{t+1}} \left(\left(R_{t+1}^L - R_t\right) L_t + R_t\right) \tag{62}$$

$$R_t^L = \frac{1 + \kappa Q_t}{Q_{t-1}} \tag{63}$$

$$MPL_t = (1 - \alpha) A_t \left(\frac{K_{t-1}}{H_t}\right)^{\alpha} \tag{64}$$

$$MPK_t = \alpha A_t \left(\frac{K_{t-1}}{H_t}\right)^{\alpha - 1} \tag{65}$$

$$R_t = (R_{t-1})^{\rho} \left(R \Pi_t^{\tau_\pi} \left(\frac{Y_t}{Y_{t-1}}\right)^{\tau_y}\right)^{1-\rho} \varepsilon_t^R \tag{66}$$

$$I_t = (1 - \lambda) I_t^o \tag{67}$$

$$K_t = (1 - \lambda) K_t^o \tag{68}$$

$$C_t = (1 - \lambda) C_t^o + \lambda C_t^h \tag{69}$$

$$\Lambda_t^h = d_t \frac{1}{C_t^h} \tag{70}$$

$$C_t^h = d_t^w w_t H_t - T_t^h - \tau \left(Y_t - Y\right) \tag{71}$$

$$d_t^w = \theta_w \Pi_{t-1}^{-\iota_w \varepsilon_w} \left(\frac{w_t}{w_{t-1}} \Pi_t \right)^{\varepsilon_w} d_{t-1}^w + (1-\theta_w)^{\frac{1}{1-\varepsilon_w}} \left(1 - \theta_w \left(\Pi_{t-1}^{\iota_w} \frac{w_{t-1}}{w_t \Pi_t} \right)^{1-\varepsilon_w} \right)^{\frac{\varepsilon_w}{\varepsilon_w - 1}} \tag{72}$$

$$\Lambda_t = (1-\lambda)\Lambda_t^o + \lambda \Lambda_t^h \tag{73}$$

$$R_t^\epsilon = (1-\rho_m)\ln(R^\epsilon) + \rho_m R_{t-1}^\epsilon + \varepsilon_{R,t} \tag{74}$$

$$\mu_t = (1-\rho_\mu)\ln(\mu) + \rho_\mu \mu_{t-1} + \varepsilon_{\mu,t} \tag{75}$$

$$A_t = (1-\rho_a)\ln(A) + \rho_a A_{t-1} + \epsilon_{A,t} \tag{76}$$

$$\lambda_{p,t} = (1-\rho_{\lambda_p})\ln(\lambda_p) + \rho_{\lambda_p} \lambda_{p,t-1} + \varepsilon_{\lambda_{p,t}} \tag{77}$$

$$\Phi_t = (1-\rho_\Phi)\,\Phi + \rho_\Phi \Phi_{t-1} + \varepsilon_{\Phi,t}. \tag{78}$$

$$\lambda_{w,t} = (1-\rho_{\lambda^w})\ln(\lambda_w) + \rho_{\lambda^w}(\lambda_{w,t-1}) + \epsilon_{\lambda_{w,t}}. \tag{79}$$

$$d_t = (1-\rho_d)\ln(d) + \rho_d d_{t-1} + \epsilon_{d,t} \tag{80}$$

A.1 Steady states

$$\Pi^* = \left(\frac{1 - \theta_p \Pi^{-(1-\varepsilon_p)(1-\iota_p)}}{1-\theta_p} \right)^{\frac{1}{1-\varepsilon_p}} \Pi \tag{81}$$

$$P^k = \frac{1}{\mu} \tag{82}$$

$$R = \frac{\Pi}{\beta} \tag{83}$$

$$d^{\pi} = \frac{(1-\theta_p)^{\frac{1}{1-\varepsilon_p}} \left(1-\theta_p \Pi^{(\iota_p - 1)(1-\varepsilon_p)}\right)^{\frac{\varepsilon_p}{\varepsilon_p - 1}}}{(1-\theta_p \Pi^{\varepsilon_p (1-\iota_p)}} \tag{84}$$

$$d^{w} = \frac{(1-\theta_w)^{\frac{1}{1-\varepsilon_w}} \left(1-\theta_w \Pi^{(\iota_w - 1)(1-\varepsilon_w)}\right)^{\frac{\varepsilon_w}{\varepsilon_w - 1}}}{(1-\theta_w \Pi^{\varepsilon_w (1-\iota_w)}} \tag{85}$$

$$mc = \frac{\varepsilon_p - 1}{\varepsilon_P} \frac{(1-\theta_p \beta \Pi^{\varepsilon_p (1-\iota_p)})}{1-\theta_p \beta \Pi^{\iota_p - 1)(1-\varepsilon_p)})} \frac{\Pi^*}{\lambda_p \Pi} \tag{86}$$

$$R^L = (0.01/4) + R \tag{87}$$

$$Q = \frac{1}{R^L - \kappa} \tag{88}$$

$$\zeta = \frac{1}{\frac{\beta}{\Pi}((R^L - R)L + R)} \tag{89}$$

$$\Phi = 1 + \frac{1-L}{(R^L/R)L} \tag{90}$$

$$M = \frac{\beta}{(\Pi - \beta\kappa)Q} \tag{91}$$

$$R^k = MP^k \frac{1-\beta(1-\delta)}{\beta} \tag{92}$$

$$\left(\frac{K}{H}\right) = \left(\frac{R^k}{mc\alpha}\right)^{\frac{1}{\alpha-1}} \tag{93}$$

$$K = \left(\frac{K}{H}\right) H \tag{94}$$

$$K^o = \frac{K}{1-\lambda} \tag{95}$$

$$w = mc(1-\alpha)\left(\frac{K}{H}\right)^{\alpha} \tag{96}$$

$$w^* = w\left(\frac{1-\theta_w}{1-\theta_w \Pi^{(\iota_w - 1)(1-\varepsilon_w)}}\right)^{\frac{1}{\varepsilon_w}} \tag{97}$$

$$Y = \frac{1}{d^{\pi}} A K^{\alpha} H^{1-\alpha} \tag{98}$$

$$I^o = \delta K^o \frac{1}{\mu} \tag{99}$$

$$I = (1-\lambda) I^o \tag{100}$$

$$C = Y - I \tag{101}$$

$$C^o = C \tag{102}$$

$$C^h = C \tag{103}$$

$$\Lambda^o = \frac{1-h\beta}{(1-h)C^o} \tag{104}$$

$$\Lambda^h = \frac{1}{C^h} \tag{105}$$

$$\Lambda = (1-\lambda)\Lambda^o + \lambda \Lambda^h \tag{106}$$

$$X^I = \frac{Y \lambda_p mc}{1-\beta\theta_p \Pi^{\varepsilon_p(1-\iota_p)}} \tag{107}$$

$$X^{II} = \frac{Y}{1-\theta_p \beta \Pi^{(\iota_p - 1)(1-\varepsilon_p)}} \tag{108}$$

$$B = \frac{\varepsilon_w - 1}{\varepsilon_w} \left(\frac{1 - \beta\theta_w \Pi^{1+\varepsilon_w\eta - \iota_w\varepsilon_w(1+\eta)}}{1 - \beta\theta_w \Pi^{\iota_w(1-\varepsilon_w)}} \right) \frac{(w^*)^{(1+\varepsilon_w\eta)}\Lambda}{\lambda_w w^{\varepsilon_w\eta} H^\eta} \tag{109}$$

$$G^I = \frac{\lambda_w^{\varepsilon_w(1+\eta)} H^{1+\eta}}{1 - \beta\theta_w \Pi^{1+\varepsilon_w\eta - \iota_w\varepsilon_w(1+\eta)}} \tag{110}$$

$$G^{II} = \frac{\varepsilon_w}{\varepsilon_w - 1} \frac{G^I}{(w^*)^{1+\varepsilon_w\eta}} \tag{111}$$

$$\bar{F} = \frac{I^o}{1 - \frac{\kappa}{\Pi}} \tag{112}$$

$$N = \frac{\bar{B} + \bar{F}}{L} \tag{113}$$

$$MPL = (1-\alpha)\left(\frac{K}{H}\right)^\alpha \tag{114}$$

$$MPK = \alpha\left(\frac{K}{H}\right)^{\alpha-1} \tag{115}$$

$$V^h = \frac{\log(C - hC) - B\frac{H^{1+\eta}}{1+\eta}}{1-\beta} \tag{116}$$

B Numerical implementation of anticipated shocks

To simulate forward guidance paths we follow the approach by Laséen and Svensson (2011), which was implemented for instance by Krause and Moyen (2016). Start with a model without news shocks that (in its linear form and no constant) can be written as follows:

$$Ax_t = Bx_{t-1} + DE_t x_{t+1} + F\varepsilon_t \tag{117}$$

with the reduced form solution

$$x_t = Qx_{t-1} + G\varepsilon_t \tag{118}$$

To conduct forward guidance in such a model, the monetary policy rule (which, for simplicity, is given by $r_t = \phi_\pi \pi_t$) will be augmented by past announcements of changes in the interest rate, that all realize in t (Harrison, 2015):

$$r_t = \phi_\pi \pi_t + \bar{\varepsilon}_t^r \tag{119}$$

with

$$\bar{\varepsilon}_t^r = \sum_{j=0}^{J-1} \nu_{j,t-j}^r. \tag{120}$$

The general notation is that the value after the comma denotes the time of announcement "$, t-j$" and the value before the comma the time until the announcement realizes ("$j,$", i.e. in $t-j+j=t$). Thus, the disturbance $\nu_{j,t-j}^r$ represents an announcement in $t-j$ that affects the policy rate in j periods. Put differently, the shock is known by the agents in $t-j$, but the change in the interest rate takes place in period $(t-j)+j=t$.[30] The term $\nu_{0,t}^r$ is similar to a monetary policy shock.

Past announcements of future interest rate adjustments become part of the state space and are denoted by ν^{t-1}:

$$\nu^t = \{\nu_{i,t-j}^r\}_{i,j\in\{1,\ldots,J-1\}}, i \geq j \tag{121}$$

This vector includes all announcements from the past, i.e. in $t-1$ or earlier

[30]However, as the model is forward-looking, such an announcement has an impact on the economy already from $t-j$ onwards.

(captured by ", $t-j$") that affect the policy rate in t or later (captured by "i,", the time until it realizes).
The model with news shocks is then an extended version of eq (117), to include a block of policy rule shocks ν_t and states ν^t:

$$[A\ A_\nu][x_t\ \nu^t]' = [B\ B_\nu][x_{t-1}\ \nu^{t-1}]' + [D\ D_\nu]E_t[x_{t+1}\ \nu^{t+1}]' + [F\ F_\nu][\varepsilon_t\ \nu_t]' \quad (122)$$

with

$$\nu_t = \{\nu^r_{0,t}, \nu^r_{1,t}, \ldots, \nu^r_{J-1,t}\} \quad (123)$$

In short:

$$\tilde{A}\tilde{x}_t = \tilde{B}\tilde{x}_{t-1} + \tilde{D}E_t\tilde{x}_{t+1} + \tilde{F}\tilde{\varepsilon}_t \quad (124)$$

with the solution given by:

$$\tilde{x}_t = \tilde{Q}\tilde{x}_{t-1} + [G\ G_\nu][\varepsilon_t\ \nu_t]' \quad (125)$$

We assume now that the central bank can actually *choose* the news shocks ν_t directly and denote such a vector with:

$$\bar{\nu}_T = [\bar{\nu}^r_{0,T}, \bar{\nu}^r_{1,T}, \ldots, \bar{\nu}^r_{J-1,T}]'. \quad (126)$$

These are J announcements for the policy rate that are announced in the beginning of period T. Importantly, households take these announcements into account, i.e. – in contrast to exogenous shocks – $E_{T-1}\bar{\nu}_T = \bar{\nu}_T$. Therefore, the h-period ahead model-based forecast $\tilde{x}_{T+h,T-1}$ is now given by:

$$\tilde{x}_{T+h,T-1} = \tilde{Q}^h\left(\tilde{Q}\tilde{x}_{T-1} + G_\nu\bar{\nu}_T\right) = \tilde{Q}^{h+1}\tilde{x}_{T-1} + \tilde{Q}^h G_\nu\bar{\nu}_T,\ h = 0, \ldots, J-1.^{31} \quad (127)$$

Since r_t is part of $\tilde{x}_t$, it holds for those periods

$$r_{T+h,T-1} = \tilde{Q}_r^{h+1}\tilde{x}_{T-1} + \tilde{Q}_r^h G_{\nu,r}\bar{\nu}_T, \quad (128)$$

with $\tilde{Q}_r$ denoting the respective row of matrix $\tilde{Q}$ and $G_{\nu,r}$ of G_ν. This implies that for a *given* vector $\bar{\nu}_T$, equation (128) determines the (anticipated) path of the policy rate. Put differently, if the policymaker wants the interest rate to

[31] Since the central bank announces its path for J periods, we focus on the forecast horizon until $T+J-1$. Harrison (2015) also focuses on situations in which $H \neq J$, where H is the forecasting horizon.

follow a pre-specified path, like

$$r_{T+h,T-1} = \bar{r}_{T+h}, \;\; h = 0, \ldots, J-1. \tag{129}$$

he has to choose the announcements $\bar{\nu}_T$ such that (129) is satisfied.

Stacking all J equations from (128) into a single matrix leads to:

$$\underbrace{\begin{bmatrix} \tilde{Q}_r \\ \tilde{Q}_r^2 \\ \vdots \\ \tilde{Q}_r^J \end{bmatrix} \cdot \tilde{x}_{T-1}}_{A^*_{Jx1}} + \underbrace{\begin{bmatrix} G\nu, r \\ \tilde{Q}_r G_{\nu,r} \\ \vdots \\ \tilde{Q}_r^{J-1} G_{\nu,r} \end{bmatrix}}_{B^*_{JxJ}} \cdot \bar{\nu}_T = \underbrace{\begin{bmatrix} \bar{r}_T \\ \bar{r}_{T+1} \\ \vdots \\ \bar{r}_{T+J-1} \end{bmatrix}}_{\bar{r}^T_{Jx1}} \Leftrightarrow A^* + B^* \bar{\nu}_T = \bar{r}^T$$

Since this is a linear model (with unique solution), one can invert matrix B^* to solve for the policy vector $\bar{\nu}_T$:

$$\bar{\nu}_T = (B^*)^{-1} \left(\bar{r}^T - A^*\right) \tag{130}$$

C Additional Figures

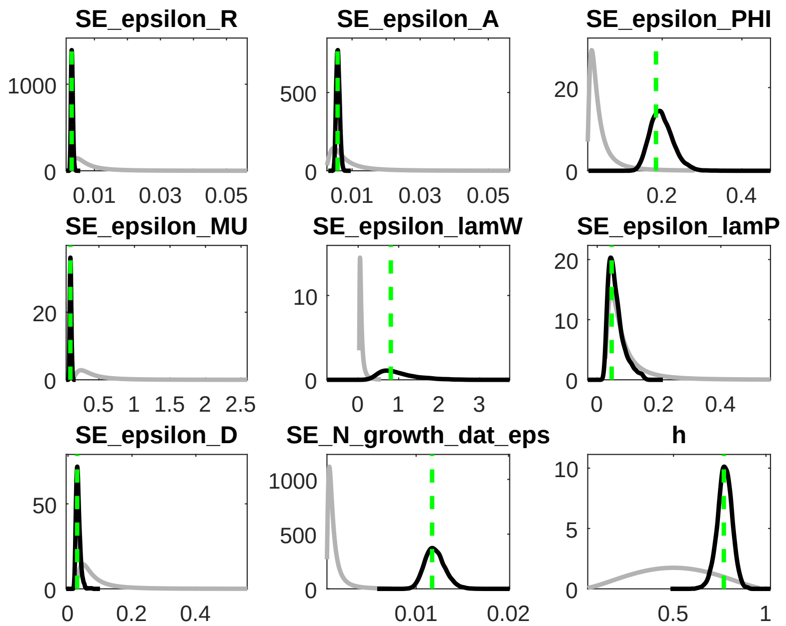

Figure 6: Prior (grey) vs. posterior (black) distribution. Green dashed line depicts the mode of the posterior distribution.

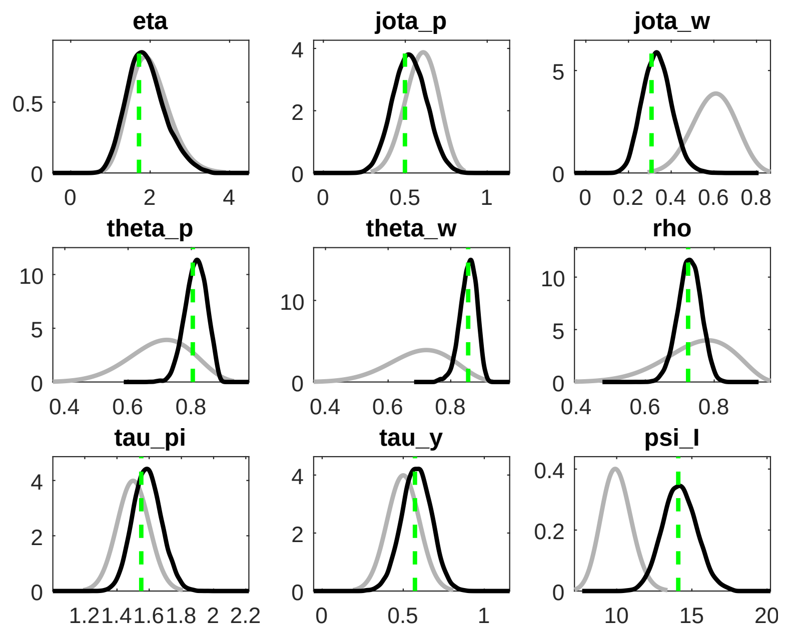

Figure 7: Prior (grey) vs. posterior (black) distribution. Green dashed line depicts the mode of the posterior distribution.

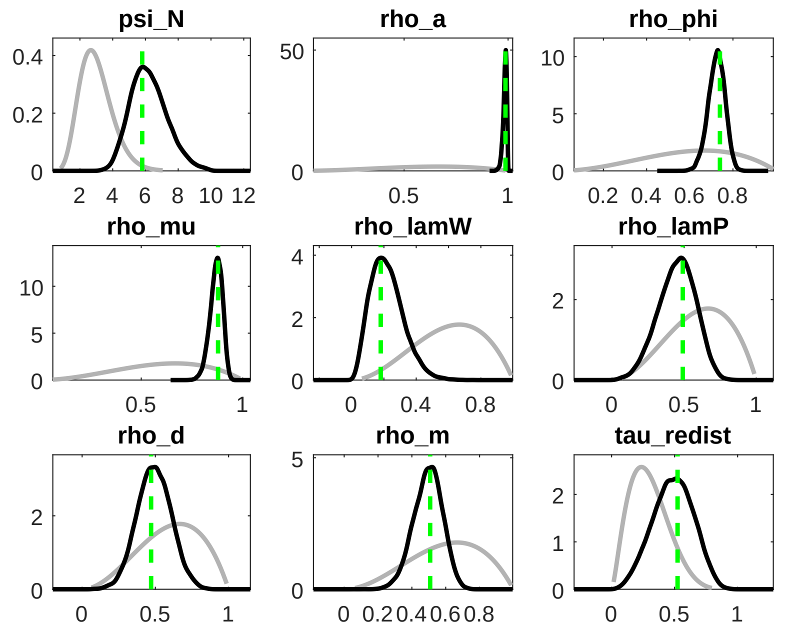

Figure 8: Prior (grey) vs. posterior (black) distribution. Green dashed line depicts the mode of the posterior distribution.

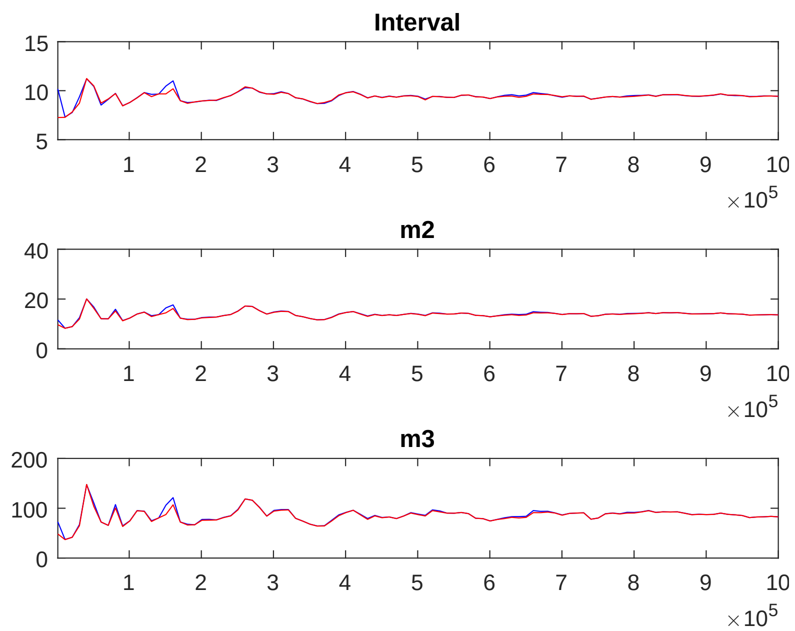

Figure 9: Multivariate convergence statistics.