Climate Change and Financial Stability: Contributions to the Debate[1]

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Abstract

Central banks have an important role to play in fighting climate change and in catalyzing policy decisions. They can contribute within their existing mandates: Price stability and financial stability are important preconditions for financial markets to allocate and price climate-related risks appropriately. In terms of policy priorities, more needs to be done within central banks' mandates to support climate policies. This includes (i) improving macroeconomic modelling and stress testing to account for climate-related risks such as non-linearities, sectoral adjustments and tipping points, (ii) enhancing transparency through disclosure standards, closing of data gaps, and building of platforms for data, (iii) strengthening financial sector resilience to account for climate-related risks and uncertainties.

I. Background

The implications of climate change have been known for decades. Climate change can cause serious damage to the global ecological, economic, and social systems.[2] Droughts and wildfires, rising sea levels, and destruction of habitat can cause major economic and humanitarian harm. Through these channels, climate-related risks for the real economy can also impair the functioning of the financial system. If these risks materialize, losses would hit the financial system, which could exhaust the system's ability to absorb losses and create adverse feedback loops to the real economy.

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[2] See e.g. Bolton et al. (2020) and Dietz et al. (2016).

The time window to address these risks is closing fast: limiting the increase in global temperatures to 1.5°C requires carbon neutrality by the year 2050 (IPCC 2018). Uncertainty is high with regard to physical risks that are related to climate change and the transition path towards a sustainable, carbon neutral economy. While policy action is needed to mitigate climate-related risks, inconsistent policies, policy reversals, and a lack of global coordination might be risk factors in their own right.

Financial systems play a key role in financing the transition to a sustainable economy, in allocating and in mitigating climate-related risks. Implications of climate change for the financial system go beyond those of typical macroeconomic shocks. The process of global warming is largely irreversible, inert, and non-linear in nature. Once critical tipping points have been reached, global warming might accelerate sharply and ultimately spiral out of control. Similar to the Covid-19 shock – a global, unexpected health shock hitting the real economy – individual market participants have limited ability to protect themselves against global climate risks.

There is thus an intense debate about the right policy approach, the policy instruments to choose and the level of international coordination needed. The role of central banks in fighting climate change is one element of this debate. At one end of the spectrum, it is argued that central banks should play a more active role in mobilizing the resources needed to finance the transition to a carbon-neutral economy and in correcting market outcomes that insufficiently reflect environmental concerns. Others argue that central banks are already operating within well-defined (legal) mandates and that broadening these mandates would not only lack political accountability but risk violations of the main objectives. According to this view, the objective of price stability should be assigned to independent institutions such as central banks.

This paper argues that central banks have an important role to play in fighting climate change and in catalyzing policy decisions affecting financial markets.[3] They can contribute within their existing mandates as price stability and financial stability are important preconditions for financial markets to allocate and price climate-related risks.

Policy instruments in the hands of central banks are no substitute for policy action taken by elected politicians who are subject to the scrutiny of the political process and societal debates. Rather than simply arguing that addressing climate change is not within the mandates of central banks, one should ask why central banks have different mandates, how central banks meeting their policy objectives complement climate policies, what the implications for the conduct of monetary and (macro)prudential policy are, and which lessons can be learned from the institutional design of central banking for other policy areas.

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[3] See also https://www.bundesbank.de/de/presse/gastbeitraege/klimaschutz-und-zentralbanken-867968.

Before addressing the role of central banks, Section 2 outlines the economics of climate change and the policy instruments to address it. Climate change resulting from carbon emissions is a prime example of negative externalities: individual choices to emit greenhouse gas fail to take into account implications for the atmosphere and the climate. In terms of policies, there is a fairly large consensus that attaching a price to carbon emissions covering all economic activities is key to addressing the externalities of private consumption and investment decisions.[4] A higher relative price of carbon-intensive activities vis-à-vis less carbon-intensive activities increases the incentive to economize on carbon emissions and to invest in climate-friendly technologies. In addition, appropriate regulatory policies targeting sector-specific needs are needed.

Section 3 turns to the role of central banks. Price and financial stability are the key mandates of central banks. By fulfilling these mandates, central banks can complement climate policies: Policies that seek to reduce carbon emissions will, ultimately, change the relative prices of carbon-intensive goods and services by shifting demand to less carbon-intensive products and services. Hence, market participants must be able to extract the correct price signals in order to act upon them. Price stability – the stability of the overall price level – is an important pre-condition for this price mechanism to work.

In addition, climate risks must be reflected, i.e. priced, on financial markets in order to gear investments towards climate-friendly investments. The correct identification of relative prices and the pricing of risks are both supported by central banks when securing price and financial stability. Assigning an explicit mandate to central banks to address climate risks would put central banks at danger of failing to achieve core policy objectives. Also, that would mean policy decisions requiring political accountability being taken by unelected technocrats.

The section also sketches institutional lessons that can be taken from the institutional organization of central banking. Time inconsistency is an inherent challenge to stability-oriented monetary policy: once a low inflation rate has been announced, governments can benefit from surprise inflation. This lack of credibility has led to institutional designs that limit discretion (Barro and Gordon 1983, Kydland and Prescott 1977, Rogoff 1985). Public trust in the stability of money can thus be backed by independent and accountable public institutions (Carney 2021).

Section 4 identifies policy priorities for central banks. This includes (i) improved macroeconomic modelling and stress testing to account for climate-related risks such as non-linearities, sectoral adjustments and tipping points, (ii) enhanced transparency through

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[4] See, for example, the Economists' statement on carbon dividends (https://www.econstatement.org). Sachverständigenrat (2019), Edenhofer and Jakob (2019) and Fücks and Köhler (2019) provide recent overviews of climate policies and policy priorities.

disclosure standards, closing of data gaps, and building of platforms for data, (iii) enhanced financial sector resilience to account for climate-related risks and uncertainties.

This paper does not cover the extensive literature on climate risks and effects on the financial system. An excellent overview of the relevant studies on the interaction between climate change and the financial system is given by Furukawa, Ichiue and Shiraki (2020) and Giglio, Kelly and Stroebel (2020).

The paper seeks to contribute to a debate on the role of climate change for central banks. Comments and suggestions are highly welcome!

II. The Economics of Climate Stability and the Role of Public Policy

a. Tragedy of the commons and the horizon

Addressing climate change requires addressing the "tragedy of the commons". The environment is a "global commons", a global pool of resources, which, unless governed appropriately, is being overused.[5] This overuse constitutes a market failure in the form of a negative externality: decisions by individuals to emit greenhouse gas cause harm to others, this constitutes a negative externality. Yet, the individual neither gets punished, nor does she pays the damaged party a compensation. This creates incentives for issuing excessive volumes of greenhouse gases. The atmosphere serves as a reservoir and public good, which can be freely used, and no-one can be excluded from its use. Property rights are not defined. This reservoir, however, becomes a scarce resource as it cannot absorb greenhouse gases infinitely without contributing to global warming. Policy intervention is thus needed to create a market for global greenhouse gas emissions to internalize the negative externality.

Managing common pool resources and conflicts that can arise requires careful institutional design (Ostrom 1990). The content and use of the common resource pool, for example, need to be defined. Collective-choice arrangements need to be made, and compliance needs to be monitored, which requires reliable and accessible data on relevant indicators. Violations of rules requires sanctions and mechanisms for conflict resolution. Finally, the interaction between the responsible local (national) level and the multinational level needs to be defined. Consistent with this, nationally determined contributions (NDCs) are a central elements of the Paris Agreement.[6]

There is also a "tragedy of the horizon" (Carney 2015): all climate-related decisions – private and public – have implications over a very long time horizon and are taken under a high

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[5] See Ostrom (1990) for design principles to manage resources in a common pool.

[6] https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs/nationally-determined-contributions-ndcs.

degree of uncertainty. Climate risks materialize over a time horizon which often exceeds the duration of private contracts. Hence, the effects of climate change on future generations are not adequately reflected in decisions taken today. This could lead to insufficient policy action being taken today. The effects of inadequate policies accumulate over time as the volume of greenhouse gas in the atmosphere increases. This necessitates stronger policy action tomorrow to limit climate change and prevent adverse and irreversible developments.

A recent ruling by the German Federal Constitutional Court emphasizes this intergenerational trade-off, as stated in its press release:[7] "*… the provisions of the Federal Climate Change Act of 12 December 2019 […] governing national climate targets and the annual emission amounts allowed until 2030 are incompatible with fundamental rights insofar as they lack sufficient specifications for further emission reductions from 2031 onwards. […] However, the challenged provisions do violate the freedoms of the complainants, some of whom are still very young.*"

b. Policy instruments

Price-based versus quantity-based measures

The key policy instrument to internalize externalities is to address carbon emissions by creating an artificial scarcity which market prices fail to signal. Governments can create this scarcity either by directly setting a price for carbon emissions (i.e. through a tax). Alternatively, they can set a ceiling for emissions and creating a market for emission rights that leads to a corresponding price.[8]

Price-based policy instruments follow the optimal taxation proposed by Pigou (1920) as an instrument to internalize negative externalities:[9] The price for emitting a unit of carbon dioxide should equal the damage done to third parties by emitting this unit. The quantity of carbon emissions evolves endogenously in this setting. Several countries use carbon taxes including the United Kingdom, Canada, Spain, South Africa, France, Argentina, Japan, and Mexico (IMF and OECD 2021: figure 1 on p. 9).

Quantity-based policy instruments, in contrast, set emission limits, and the price for carbon emissions evolves endogenously. Following Coase (1960), emission limits establish property rights to the global commons. At the current juncture, Emissions Trading Systems (ETS) have been adopted by 35 countries; 31 of them are EU countries participating in the EU Emission Trading System (EU ETS) which does not cover all sectors yet.

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7 https://www.bundesverfassungsgericht.de/SharedDocs/Pressemitteilungen/EN/2021/bvg21-031.html.

8 See e.g. Kolstad (2011).

9 See also Edenhofer, Franks and Kalkuhl (2021).

Choosing between price-based and quantity-based policies is not straightforward.[10] In terms of the information needed, price-based policy instruments are more demanding than quantity-based instruments. Price-based policies require computing by how much prices for emissions have to change to reach a certain emissions target, who will be affected, and how strong responses to price changes will be. The price may have to be recalibrated successively if reductions of emissions are insufficient. Quantity-based regulation starts from a quantification of emissions to be reduced, and emission rights are then auctioned off. The price for emissions evolves endogenously. This requires tracking whether emissions are in line with the emission rights and monitoring compliance. Hence, while quantity-based instruments ensure that a certain emission level is reached, volatility of prices and uncertainty for consumers and investors can be higher than under price-based regulation.

In practice, governments choose combinations of price- and quantity-based policies, differentiating also between sectors. In Europe, for example, the EU ETS covers energy-intensive industrial sectors as well as electricity and heat generation. Other important sectors such as housing are exempt but covered by other regulatory measures like emission standards. In addition to policy instruments that directly limit carbon emissions, a number of instruments that indirectly affect emissions are used. These include energy taxes, subsidies for the production of renewables, or setting technological standards. There are indeed good reasons for using a mix of policy instruments as many decisions that are needed to move the economy closer to net zero emissions of long-lived greenhouse gases by 2050 are unlikely to respond to marginal price changes alone (Hepburn, Stern and Stiglitz 2020).

Irrespective of the instruments chosen, embarking on a path to a net zero carbon emission economy leads to a significant repricing of assets across countries and sectors. Claims on activities that heavily use fossil fuels are likely to be devalued, and some assets may even become “stranded” (Huxham, Anwar and Nelson 2019; Holz et al. 2018). Assets in the form of global coal, gas and oil reserves would lose in value (McGlade and Ekins 2015), as would production processes that extensively use such resources and that have limited substitutability across inputs.

How smooth the repricing of assets and the adjustment of financial flows will take place depends on the clarity of policy signals and the availability of information. As a benchmark, assume a fully credible, time-consistent, internationally agreed path for carbon emission prices. In this case, all investment and consumption decisions would be taken on the basis of the correct level of relative prices and would internalize climate-related externalities. Information problems would be drastically reduced as investors would not have to do their own (country-specific) calculus of climate-related risks but observe input and output prices only.

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[10] See Weitzman (1974) for a discussion of the optimality between price- and quantity-based regulation.

Of course, we are far away from such an ideal world. There is no carbon price covering all sectors as a crucial information device. Investors thus require information on the carbon intensity of inputs and outputs, on exposures to climate policies, on reactions of firms to such policies, and on potential legal risks if disclosure is insufficient. International initiatives aimed at both coordinating policies and enhancing transparency concerning climate-related risks, are thus crucial to close information gaps.

R&D subsidies

Subsidies for research and development are one important instrument in the toolbox. The shift away from carbon-intensive production patterns requires investment into new technologies. The private sector may underinvest into new technologies and insufficiently account for positive knowledge spillovers. While this potential underinvestment is a general market failure, it is particularly acute in the case of R&D into clean technologies due to the global negative externalities of greenhouse gas emissions. Policy instruments addressing this market failure target research and development (R&D) through patents and similar protections of property rights. Yet climate-related R&D might not sufficiently account for the very long-term horizons over which the social effects of such investments materialize. There may thus be a role for the government to either subsidize basic research or to create a protected market segment in which new technologies can achieve market maturity. An optimal policy mix would combine carbon taxes and research subsidies (Acemoglu et al. 2012).

Behavioral enhancements

Voluntary private sector initiatives can enhance the effectiveness of policy instruments but cannot substitute political decisions.[11] At the same time, once policy changes have been taken, behavioral changes can be important levers. Frank (2020) argues, for example, that the effects of carbon taxes can be amplified through behavioral contagion. The direct effect of changes in relative prices through taxes can be reinforced by indirect effects if social feedback loops encourage consumers to buy relatively more environmentally-friendly products. Frank draws an analogy to smoking, which was reduced through higher prices for cigarettes and better recognition of health hazards, but also to a large extent through social feedback effects.

The importance of behavioral enhancements differs across polices instruments. Schmidt and Herweg (2021) show that price and quantity regulation are not equivalent when moral concerns of consumers are taken into considerations. Moral concerns can affect consumption decisions in terms of the willingness to adjust travel patterns or to install solar

[11] Tirole (2019: 36), for example, has argued"*… there is nothing wrong with socially responsible investment (SRI), but SRI by definition follows a decentralized approach. In particular, I can't help noting the incongruity that arises when governments do not dare to price carbon, yet ask business to behave 'as if'.*"

panels. Under price-based regulation, these moral concerns matter, as morally concerned consumers are induced to consume less, and behavioral adjustment reinforce the effects of policies. Emissions decline by more. Under quantity-based regulation, such as a market for emissions, in contrast, the quantity of emissions is fixed, and behavioral enhancements are less effective.

Empirical evidence supports that feedback effects between preferences and climate-related outcomes are relevant. Furukawa, Ichiue and Shiraki (2020) cite studies on pricing patterns in housing markets which show that stronger preferences of institutional investors for social and environmental performance affect investment behavior. While property prices insufficiently account for climate risks, such underpricing of risks tends to be smaller in communities with a higher awareness of environmental issues.

c. The time (in)consistency of climate policies

Left unregulated, markets would fail and cause an excessive level of greenhouse gas emissions. Economic policy thus needs to design an institutional framework that allows carbon emissions to be priced and regulated. This would allow consumers and producers to align their plans with this set of policies, and it would stabilize macroeconomic responses to climate policies.

This framework needs to take into account that climate policies run the risk of policy reversals and time inconsistencies as current policymakers cannot tie the hands of future policymakers. There are two important trade-offs that policymakers have to deal with: those between short-term and long-term effects, and those between private and social costs and benefits.

Take the trade-off between the short- and the long-term effects first. In the longer term, effects of the reduction in carbon dioxide on the real economy and of avoiding the damage done by global warming are clearly positive. In the short term, however, markets for capital and labor may not adjust sufficiently fast for industries to shift away from carbon-intensive production. Assets of producers and extensive users of fossil energy may have to be written off, implying losses to investors in these industries and to economies that mostly rely on the extraction and export of fossil fuels. This may have repercussions for the financial system if exposures are large and if risks are insufficiently diversified. Labor markets have to accommodate the declining demand for workers in carbon-intensive industries and the relocation to less carbon-intensive industries.

At the current juncture, carbon pricing is insufficient in terms of its sectoral coverage and in terms of reaching emission targets. The optimal policy response would be to adjust policies now in order to reach those targets while using other policy tools such as social policy to cushion the short-term costs on those affected the most. Postponing such policy decisions might look less risky and costly in the short run. However, it may have a longer-run price tag

as climate-related risks increase and as policy action needs to become more drastic. Aggravating climate risks may run the risk of sudden policy reversals, with the potential to destabilize real economic activity and render past investments obsolete.

Policy decisions are additionally affected by the different calculus of private versus social costs and benefits. Individuals directly feel and observe the effects that policies have on their personal lifestyle, but climate-related effects are not very tangible. Global climate policies differ from local environmental policies that seek to improve local conditions that are tangible – a river is cleaner, and the air becomes less polluted. Over time, the political consensus to maintain climate policies may thus change. Even though governments may announce a gradual path for the price of carbon emission today, it might thus be optimal for future governments to reverse those decisions. This, in turn, creates uncertainties for households and firms when taking long-term investment decisions.

Hence, mechanisms are needed which allow the interests of future generations to be taken into account while at the same time ensuring that policy decisions taken today are not reversed in the future. These mechanisms include clear and accessible communication on the effects of climate polices and on the measures taken to mitigate undue private costs.

III. Implications of Climate Change for Central Banks

The discussion so far has shown that climate policies are about addressing a global externality through a set of policy instruments. Managing the associated trade-offs requires political accountability as well as institutions that can contribute to international coordination and reducing time inconsistency problems.

There is an intensive discussion about the role of central banks in addressing climate change: should central banks actively pursue climate objectives or would this go beyond their mandates? [12] This section discusses the mandates of central banks, their contributions to climate policies, and lessons from the institutional design of central banking.

a. What's within the mandate of central banks?

Central banks' core mandate is to pursue price stability. Yet a survey conducted among 107 central banks also shows that about half of the central banks have the mandate to support government economic policy or economic development either as a primary (22%) or as a secondary objective (31%) (NGFS 2020). Only one quarter of all mandates comprise specific provisions to support sustainable economic development. A majority of central banks (73%) envisage taking climate-related measures: *Protective* measures aim at mitigating financial risks and safeguarding financial stability; *proactive* measures aim at ensuring a smooth

[12] See Weidmann (2020) or Fuest (2020).

transition to a low-carbon society including price stability, financial stability, and the mitigation of market distortions.

The survey reveals central banks' focus on price stability while recognizing that central banks feel obliged to contribute to broader policy objectives. To rationalize this division of labor, Table 1 compares three policy areas and policy objectives – two of which are in the realm of central banks (price stability and financial stability), and one of which is not (climate stability). The table classifies these policies around the economic problems addressed, the policy objective, the policy instruments, the institutional design, the analytical approaches, and the time horizon.

b. Why do central banks have different mandates?

So *why* are climate policies not within the mandate of central banks? The main reason is that the policy problem is different. The specific role of central banks and the well-defined mandate to ensure price stability have evolved over time. They are a response to the recognition that, without a clear separation between monetary and fiscal policy, there is the risk that the objective of price stability will be subordinated to other economic objectives pursued by the government. This may leave inflation at a suboptimally high level, with adverse consequences for income distribution, the reliability of price signals, and, ultimately, economic growth. Eventually, monetary policy was thus delegated to technocratic, independent institutions with a well-defined mandate. In exchange for this independence and the lack of direct democratic accountability, central banks are limited in the use of their policy instruments.

Climate stability, in contrast, is a much more multi-faceted problem, requiring policy instruments spanning across all policy areas, having a much longer time horizon, and requiring a much more interdisciplinary approach. Price stability, for example, is defined over the medium term, and there is ample empirical evidence that monetary policy has no significant impact on real economic outcomes such as economic growth over the longer term.

This needs to be taken into account when designing the mandates of institutions tasked with climate policies. Tirole (2019: 37) has argued that "*agency independence is not appropriate for broad societal choices*". Similarly, policies that cannot be linked to clear, measurable objectives such as environmental policies may lack important preconditions for delegation to independent authorities (Tucker 2018: 15).

Agency independence, ultimately, requires a discussion about the preferences of society for certain policy objectives. Climate action, for example, is only one of the 17 UN Sustainable Development Goals. Delegation will be credible only if society broadly shares preferences for the objectives of an independent institution. Tensions could arise if societal preferences and those of independent institutions do not match. What if, for example, a consensus emerges

in society that that elected national governments are not taking sufficient action to mitigate climate-related risks – should (non-elected) central banks fill the void?

The public's willingness to delegate key responsibilities for climate policies with core implications for economic structures and income distribution to independent technocrats akin to central banks is debatable. Financial stability policies, which will be discussed below, are a case in point. Precisely because macroprudential policy decisions can have distributional consequences, such decisions are typically not entirely within the remit of central banks.[13]

This leaves us with the question of what central banks can do *within* their mandates to support climate policies. Narrowly defined, the answer to this question should start with central banks' own operations. Central banks are large organizations that engage in risk and asset management, they have operational activities and reporting obligations. All these operations need to follow the same environmental and climate standards as apply to the private sector. Being accountable to the general public, central banks should indeed be leaders rather than followers in this realm. Moreover, empirical studies support of the hypothesis that behavioral enhancements can have relevant effects. In this sense, also action taken by central banks to enforce climate-related disclosures can likewise play an important catalytic role (Weidmann 2020).

c. How can price and financial stability complement climate policies?

But there is also a broader answer to the role of central banks in climate policies which goes beyond operational aspects. Recall the conditions needed for the transition to a carbon-neutral economy: consumers and investors need to react to relative price signals and to be able to appropriately price climate-related risks. Ensuring that both conditions are met is actually within the core mandate of central banks.

Take price stability first. Given the long history of stable prices that advanced economies have enjoyed over the past decades, it is easy to underestimate their importance. Yet, the higher and the more volatile the inflation rate, the more difficult it becomes to extract relative price signals (Phelps et al. 1969). This point is particularly relevant for the debate on climate change and the transition to a net zero carbon emission economy: capital investments in many industries have very long time horizons and are taken under an extremely high degree of uncertainty. Eliminating as much noise as possible from price signals received by investors and consumers is thus key. And this is exactly the role of central banks pursuing price stability objectives.

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[13] See Edge and Liang (2020) for an analysis of the governance structure of macroprudential policy, including the role of central banks, in the context of decisions on the countercyclical capital buffer.

Central banks' large-scale asset purchase programs may seem to open the avenue for yet another role: Couldn't central banks contribute to channeling financial investments into green assets? Apart from the weak link between real investments in green technologies and the funding structure of these investments, there is another conceptual flaw in this argument. Although central banks are large buyers on secondary markets for government bonds, their purchases do not constitute net wealth of the private sector (Benigno 2016). Purchases of securities through central banks affect output and inflation through a portfolio rebalancing effect that reallocates risks in an economy from the private sector to the public sector, i.e. central banks' balance sheets. Assessing the full effects of asset purchases over time thus needs to take into account the fiscal implications: if losses on central banks' balance sheets materialize in the future, profits that can be transferred to fiscal authorities decline. If fiscal authorities shift the burden to the private sector through higher taxes, there is no net wealth effect. Similarly, Reis (2013: 2) has argued that "*the central bank's main power is to raise its inflation target, but otherwise the balance sheet gives little leeway to pursue other goals.*"

In this sense, an increase in the purchases of "green assets" through central banks would not change the private sector's net wealth that can be invested into sustainable investment projects.

Central banks' contribution to financial stability is a second condition for successful climate policies. Taking investment decisions that gear the economy towards greater sustainability requires good information on first moments (prices) but also on second moments (risks). By ensuring that financial markets perform their role for the real economy, financial stability policies provide the basis for sound risk assessments. Such policies are no panacea, of course. They are no substitute for other policies that are needed in order to embark on the path to zero net carbon emissions and mitigate transitional and physical risks. But macroprudential policy can ensure that vulnerabilities to risks are identified and mitigated such that shocks – materializations of transitional or physical risks – are not amplified within the financial system. We will discuss this in more detail in Section IV.

d. What are lessons from the institutional design of central banks?

In terms of institutional design of climate policies, there are a few lessons that can be learned from the design of central banking mandates.

First, creating independent institutions can help to address issues of time inconsistencies and the risk of policy reversals due to electoral cycles. Mandates of independent institutions should be confined to policy areas where policy objectives and instruments are well-defined. This is the case for price stability mandates. The specific nature of central bank independence has been argued by Tucker (2018: 59): central banks are the *suppliers* of one

public good (price stability) and *preservers* of a common good (financial stability). This, in turn, limits their mandates.

To address the time inconsistency problem inherent in climate policies, Helm, Hepburn, and Mash (2003) draw analogies with the institutional setup for monetary policy. Along those lines, Fücks (2013) proposes an "International Climate Bank", which would borrow institutional features from modern central banks rather than using central banks to achieve two objectives. This International Climate Bank would issue carbon emission rights and limit the issuance of such rights if climate stability were at risk. It could be the custodian for global climate agreements and would require political legitimacy to assume such as role.

Similarly, a recent G30 report written under the leadership of Janet Yellen and Mark Carney argues that credibility of climate policy can be enhanced by borrowing lessons from the institutional design of central banking: "*Governments can, however, delegate the calibration of the instruments that are necessary to achieve this target to 'Carbon Councils.' Delegating these responsibilities helps insulate decisions with significant long-term implications from short-term political pressures.*" (G30 2020: p. xiv).[14]

Second, independence reaches its limits whenever political accountability is needed. This is the case for financial stability mandates: Because financial stability policies can have distributional consequences, they are not assigned solely to central banks but also to institutions that are politically accountable.

Third, policy coordination is needed internationally to mitigate spillovers and negative externalities. In central banking, policy institutions such as the International Monetary Fund have been established to address the risk of competitive devaluations and preserve the stability of the international monetary system. To achieve this objective the IMF monitors regularly member countries policies in structured surveillance process, provides policy advise and technical expertise. Climate change is a global challenge requiring international coordination. Use of the global commons needs to be appropriately priced, and enforcement mechanisms are needed to align the incentives of countries accounting for the bulk of global greenhouse gas emissions with those most heavily affected by climate change. International treaties share the fundamental problem of lacking enforcement mechanisms. The treaties such as the Conference of Parties' Paris Agreement and the G7/G20 Agreement have formulated goals, but there is no sanction mechanism, and policy action remains largely voluntary.

[14] https://group30.org/images/uploads/publications/G30_Mainstreaming_the_Transition_to_a_Net-Zero_Economy.pdf.

IV. Climate Change and Financial Stability

a. Financial stability as a common good

Financial stability is a policy objective which has been defined explicitly only after the global financial crisis. A stable financial system is able to perform its main functions: the allocation of savings, the funding of investment, the pricing and allocation of risks, and ensuring the smooth functioning of the payment system. A resilient financial system should neither cause nor excessively amplify economic shocks.

Climate-related risks can aggravate financial stability risks. This risk is acute if climate risks were not sufficiently factored in by market participants. This can lead to a significant repricing of financial assets and expose existing vulnerabilities in the financial system arising, for example, from excessively high levels of private sector debt. If climate-related risks materialize, leading to losses in the financial system, the financial system needs to be sufficiently resilient and to absorb those losses. This, in turn, would have negative feedback effects on the real economy and aggravate the effects of climate-related risks.

Climate-related risks impacting the real economy may be amplified in the financial sector through different channels. Changes in prices of climate-sensitive assets can induce losses and trigger large-scale shifts in portfolios, further reinforcing price adjustments. The effect can become a systemic issue if portfolios of many investors are exposed to similar risks. Akin to the Covid-19 shock, asymmetric impacts on individual firms and sectors can lead to solvency problems and expose the financial sector to concentrated risks. Hence, surveillance of amplification focuses on the channels through which seemingly small shock can become systemic: concentration of risks in individual institutions or market segments, common exposures, and connectedness.

Safeguarding financial stability is about addressing a common resource problem characterized by hidden action on part of financial institutions and regulators (Tucker 2016). Financial institutions may, for example, engage into risky activities that have negative implications for the financial system, become highly connected or exposed to similar risks. Such systemic risks are insufficiently factored into markets' risk assessments. Like in the case of climate policies, mechanisms and regulations to internalize negative externalities are thus necessary.

Financial stability and price stability share common features but differ especially regarding one key characteristic (Tucker 2018: 59). Price stability, i.e. stability in the value of money, is a public good characterized by non-excludability and non-rivalry. Likewise, financial stability is non-excludable in the sense that no market participant can be exclude from its benefits. All financial institutions benefit from financial stability.

However, financial stability is rivalrous: the resilience of the financial system can be "consumed" and thereby diminishes over time. If a small number of market participants builds up excessive levels of debt or exposures to macroeconomic risk factors, this may not threaten the stability of the entire financial system. But if debt continues to increase and if vulnerabilities reach into all parts of the financial, even seemingly small external shocks may trigger system failure. Similarly, global warming can trigger irreversible events as greenhouse gases accumulate. There is an important difference, however, because financial stability can be restored within a certain time span while climate change is long lasting and not reversible for generations.

In any case, ensuring that stability of the system does not diminish over time requires appropriate regulation. However, financial institutions may respond to regulations through regulatory arbitrage that increases their systemic footprint; regulators may be under pressure from local interest groups to allow domestic institutions to take on higher risk than what is consistent with the international standard.

This calls for a benchmark standard for regimes to preserve stability globally, and not locally (Cecchetti and Tucker 2015). In practice, financial stability work is thus largely a national responsibility with coordination mechanisms at the supranational level (e.g., European System Risk Board) and at the international level (e.g., Financial Stability Board).

Financial stability and climate stability thus share common features: the atmosphere and financial resilience are global commons that may be overused by individual market participants. Policy interventions are thus necessary to address this market failure by internalizing externalities. In qualitative terms, both externalities are global and have important non-linear features. Similarly to the regulatory arbitrage of banks, carbon leakage and the relocation of production activity to countries with lower emission standards can undermine local climate policies. In quantitative terms, however, climate-related risks and financial stability risks differ. Climate risks are of a global scale and significantly more persistent than financial stability risks. Economic history shows that financial crises have been recurring time and again, and that these crises had long-lasting output effects (Reinhardt and Rogoff 2009). However, the effects of financial crises are nowhere near as devastating globally and as long-lasting as climate risks which materialize.

b. The role of financial markets

Well-functioning financial markets contribute to addressing climate-related risks. The first role is to align patterns of savings and investment with the objective of reducing carbon emissions. Assessing the financial resources needed to finance the transition to an economy with net zero carbon emissions is difficult: A production process relying heavily on energy might be rather carbon-intensive given the current mix of energy supply. Switching this production process to being climate-neutral would not require specific investments if energy

inputs were climate-neutral. However, past investments in outdated technology such as coal power plants might have to be written off almost entirely. Assessing the specific investment needed for the transition to a greener economy thus requires an estimate of the capital stock that is being devalued as a result of climate change (and of mitigating policies) in excess of the normal depreciation of capital.

Providing insurance against the financial impact of climate-related risks is a second key role of the financial system. This requires a transfer of risk from those unwilling to hold this risk to those willing. Generally, the unprecedented nature of climate-related risks makes it difficult to adequately price them (FSB 2020). In this regard, central banks can contribute to an adequate pricing of risk by setting standards in the measurement of risks and regulating disclosure to account for climate-related risk factors.

Different types of financial institutions can complement each other. Financial market participants differ in terms of the information that they have available as well as their ability to manage assets and liabilities. Banks, for example, might have superior ability to assess credit-related risks than insurance companies; institutions with longer-term liabilities are in a better position to bear longer-term, climate-related risks than banks which are funded through short-term deposits.

Not all financial instruments are equally suited to manage climate-related risks. The time horizon for climate-related investments is longer than for many other investments, and investments are made with a high degree of uncertainty. This speaks in favor of financial contracts such as equity finance rather than bond finance as the latter often has both fixed returns and a fixed time horizon.[15] For that reason, the European Capital Market Union can play an important role in funding a transition to a low-carbon economy as it seeks to strengthen and deepen equity markets in Europe (de Guindos 2020).

c. Surveillance and regulation of climate-related risks

Are climate-related risks a special source of risk? Answers to this question differ. According to Bolton (2021), climate-related risks are different from the types of risk that markets and regulators are typically dealing with; the nature and implications of climate-relate risks constitutes a (series of) “Green Swan” event(s). Cochrane (2021) states, to the contrary, that climate change poses no relevant risk to the financial system in the sense that the financial system and banks in particular would be subject to sudden losses or a run on short-term debt. The Basel Committee for Banking Supervision has recently published reports arguing that drivers of climate risks can be captured in traditional financial risk categories, but that additional progress is needed to better estimate these risks.[16]

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[15] On the role of equity finance to the climate transition, see De Haas and Popov (2019).

[16] https://www.bis.org/press/p210414.htm.

In line with this, the Deutsche Bundesbank (2019) argues that climate-related risks reach the financial sector through existing categories of risk, including business, credit, market, insurance, or legal risk. Still, the implications of climate change for risk dynamics and magnitudes are different from the implications of more standard macroeconomic shocks because of the inherent non-linearities and tipping points.

Climate-related risks are typically classified into two broad categories. Physical risks are related to the increasing frequency and severity of climate-related weather events and the effects of long-term changes in climate patterns. Transitional risks result from a transition to a less carbon-intensive economy, including policy and regulatory changes, technological breakthroughs or changes in social norms (Bolton et al. 2020). These risks interact with each other. The more severe the impact of climate change for the real economy, the more urgent is the need for policy changes to manage the transition.

While physical and transition risks affecting traditional risk categories, there is no simple relationship between current carbon-intensity of economic activities and risks represented to investors. A low degree of carbon intensity of a firm or economic activity does not automatically imply that financial risks are lower compared to higher carbon intensity. From a financial stability perspective, one key question is whether physical and transitional risks are generally underestimated, which would in turn give rise to systemic risk in the financial sector.

To what extent are climate-related risks – physical and transitional – priced in financial markets? Differences in the risk premia on assets labeled “green”, i.e. claims on activities associated with low carbon emissions, versus those labeled “brown”, i.e. those associated with high carbon emissions, provide answers. Investors can be expected to demand higher risk premia for brown assets compared to green assets, which serve as a hedge against climate risk.[17]

Furukawa, Ichiue and Shiraki (2020: 33) provide a comprehensive review of the literature. They conclude that real estate and stock prices do not fully reflect physical climate risks and that there is mixed evidence on the premia of green bonds. At the same time, local weather events change investors’ perception of risks, and enhanced disclosure and communication contribute to a better pricing of climate-related risks. They conclude that pricing today does not adequately reflect climate-related risks. This could hinder adaptation and mitigation and lead to a sharp repricing when risks materialize.

The advisory council to the German Ministry of Finance discusses the effects of ESG (Environmental, Social, Governance) criteria for the real investment decisions affecting climate risks (Wissenschaftlicher Beirat BMF 2021). The report argues that, in well-

[17] See Pastor et al. (2020).

functioning financial markets, green bonds or other financial vehicles per se have little impact on the real investment decisions affecting climate risks. Sustainability considerations can play a role if active investment strategies have an impact on firm-level investment decisions. In any case, the effects of sustainability objectives should be assessed against real investment decisions rather than the financing side.

Generally, the extent to which pricing on financial markets has reflected climate-related risks appears to be rather limited and insufficient in obtaining an efficient market outcome (Bolton et al. 2020). Limited pricing of externalities caused by carbon emissions and uncertainty about future climate policies are the main reasons for this. This, together with the fact that severe physical impacts of climate change materialize only over the long term, limits the ability of financial markets to price related risks and reach an efficient allocation of capital.

Containing risks to financial stability is key for financial markets to play their role in managing the transition to a climate-neutral economy. Macroprudential surveillance of climate-related risks has three objectives: to identify relevant climate-related risks, to analyze the vulnerabilities and exposures of the financial system to these risks, and to assess whether preventive policies to reduce and mitigate systemic risks is necessary.

As transitional and physical risks have implications for traditional risk categories assessed by microprudential supervisors, there is a need to ensure that banks and other financial institutions incorporate climate-related risks into their risk management. In the European Banking Union, the Single Supervisory Mechanisms (SSM) adopted a risk-based supervisory approach to climate change and environmental degradation. Microprudential supervision ensuring that banks and financial firms do incorporate climate related risks is a necessary but not a sufficient condition for financial stability. Macroprudential authorities thus also started to assess potential climate-related vulnerabilities to better understand if there are systemic risks related to physical and transition risks. The main obstacles for individual risk management as well as prudential oversight and supervision is the unavailability of suitable data for carbon emissions at the firm level. There is therefore a need for common (minimum) standards for disclosure of climate-related information that can be used by financial sector as well as micro- and macroprudential policymakers.

V. Policy Priorities for Central Banks

Climate change is the most severe challenge facing today's societies. Overuse of a global common good, the climate, will have devastating, long-term effects for societies which go beyond effects of global health or financial crises seen so far. Current prices for carbon emissions insufficiently reflect the scarcity of environmental resources. National policy

decisions and international agreements are needed that effectively limit emissions of greenhouse gases.

High uncertainty over the effects of climate change necessitates a reliable compass. By fulfilling their mandate to secure price stability and financial stability, central banks provide essential conditions for climate policies to succeed. Stability of nominal prices is important for firms and households to receive, interpret, and act upon relative price signals. Stable financial markets are needed to price and allocate climate-related risks and for financing the transition to a carbon-neutral economy.

In addition, elements of the institutional set-up of independent central banks may be useful for climate policies. In central banking, time inconsistency problems have been addressed by assigning the price stability mandate to institutions that can choose policy instruments independently from political pressure. This independence of central banks has been an important factor contributing to price stability.[18] Similar elements can be useful in designing institutions that deal with the time inconsistency and potential lack of credibility of climate policies.

Mandating central banks to pursue climate stability objectives directly can, in contrast, lead to policy trade-offs that could ultimately put the fulfillment of their core mandates at risk: the promotion of investment into green technologies through regulatory incentives might, for example, jeopardize financial stability if investors have inadequate resources to absorb losses. Also, assigning policy decisions which require democratic accountability to non-elected technocrats would be problematic.

Yet, in order to better play their roles, to complement and to catalyze climate policies, central banks need to massively improve their analytical tools and data infrastructures. We see the following policy priorities for central banks.

a. Improving macroeconomic models

Standard macroeconomic models in the toolbox of central banks cannot address many of the relevant climate-related issues. Dynamic stochastic general equilibrium models, for example, focus on short-term volatility around long-term trends but do not model these long-term trends. Also, the sectoral dimension of these models is typically not very strongly developed. The role of carbon taxes for macroeconomic dynamics, in turn, is often modelled without taking the role of financial markets into consideration (Bolton 2021). This suggests a number of priorities for macroeconomic modelling of climate risks.

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[18] See Carare, de Resende, Levin and Zhang (2021) for a recent study on the role of monetary policy frameworks, including central bank independence, for low income countries.

First, in order to capture the effects of climate-risk for the real economy, macroeconomic models need to incorporate physical and transitional risks. Transitional risks include climate policies such as the impact of emission pricing, as well as technological innovation, and other factors shaping the transition.

Second, scenarios need to be developed that allow analyzing the correlation between economic and climate variables under different policy assumptions. The Network for the Greening of the Financial System (NGFS) has developed an analytical framework for assessing climate-related risk for financial stability based on climate scenarios (NGFS 2020a). The scenarios can integrate physical damages induced by climate change, potentially disaggregated at a geographical or sectoral level. The scenarios can also be translated into macroeconomic and financial stress scenarios.

Third, climate stress tests can help raises the awareness of existing vulnerabilities. But stress testing with a typical time horizon of a few years also has its limits and may lead to either a false sense of security or signal a misplaced need for action.

Fourth, incorporating climate-related risks into the analysis of financial stability requires interdisciplinary work across fields such as economics and climate research. A portfolio of tools and models, including interdisciplinary approaches, is needed in order to assess climate-related risks. One important analytical toolbox are historical counterfactual simulations, which start from responses to regional natural disasters that have happened in the past and simulate alternative adjustment paths.

Given that climate-related macro-models and climate stress tests are an emerging field, it is crucial at this juncture to build up an infrastructure that makes best use of the available evidence and allows for learning from experience. Going forward, it will be important to define relevant analytical questions, to take stock of the economic modelling approaches that exist, and to identify gaps. A repository of studies and empirical models can be useful to provide low-cost access to relevant literature, codes, and data. Central banks can play an important role in this regard by providing platforms for sharing information and tools.

b. Enhancing transparency and information systems

Information on the exposure and vulnerability of firms to climate-related risks is key to pricing these risks. This requires information on emissions associated with production, emissions embodied in production inputs, and emissions created in the entire life-cycle of produced output.

Timely availability and access to relevant information are crucial for different stakeholders: Policymakers require information on environmental exposures to calibrate policy instruments, markets require information to price risks accordingly. Analysts in private and public institutions need to be able to assess the firm-level, sectoral, and macroeconomic

implications of climate change and of policy measures. Information on climate-related risks and the coordination of different disclosure standards is thus a key public good.

Accordingly, many international activities have been launched that identify relevant data gaps and describe strategies towards closing these gaps. In May 2021, the Network for the Greening of the Financial System has published a progress report (NGFS 2021), and the Financial Stability Board (FSB) is working on a roadmap for dealing with climate-related issues, including closing of data gaps.

Various rating agencies provide Environmental, Social and Governmental ratings. Yet, absent standards for harmonization, these ESG scores differ considerably (Berg et al. 2020). The Task Force on Climate-related Financial Disclosures (TCFD) has developed voluntary, consistent climate-related financial disclosure standards. At the national level, the German Sustainable Finance advisory council has made proposals on how to close related data gaps (Sustainable Finance Beirat 2021). These initiatives aim at coordinating the many grass-root and focused initiatives aimed at improving data collection and disclosure.

Closing data gaps has also been a top priority after the global financial crisis. More than ten years ago, the crisis revealed gaps that impaired the understanding of relevant parts of the financial such as derivative markets and interdependencies in the system. In the aftermath of the crisis, the G20 has therefore initiated a large-scale initiative to close data gaps, and has since then monitored its implementation.[19]

The public sector indeed has a key role to play in terms of coordinating work on data and speeding up the process. This is even more urgent than following the global financial crisis, as better data is immediately relevant for market participants. Timely access of relevant information on climate related risk for all stakeholders is crucial. This calls for an agile process which combines elements of (i) analyzing current data availability, (ii) providing guidance for collecting relevant data that are currently missing, and (iii) establishing platforms that can be used to disclose and share relevant data, both currently available and newly collected data.

Timely implementation can be achieved by initiating these steps in parallel rather than sequentially. In this regard, lessons may be learned from international initiatives aimed at speeding up the development of vaccines against Covid-19. In April 2020, the WHO published a statement for collaboration on Covid-19 vaccine development, stating that: *"[…] We will continue efforts to strengthen the unprecedented worldwide collaboration, cooperation and sharing of data already underway. […]"* [20]

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[19] https://www.imf.org/external/np/seminars/eng/dgi/index.htm.

[20] https://www.who.int/news/item/13-04-2020-public-statement-for-collaboration-on-covid-19-vaccine-development.

Statistical offices and central bank statistics have an important role to play in promoting the necessary information infrastructure. Central banks should particularly focus on information related to financial markets. They can promote data generation on exposures to transitional risks by expecting or even mandating the disclosure of information through their supervisory mandates. Moreover, by applying disclosure standards in their own policies, central banks can catalyze the adoption of those standards and lead by example.

c. Enhancing financial sector resilience

In terms of policies, strengthening resilience in an uncertain environment should be a priority. While risks can be priced in financial markets, general uncertainties cannot. This limits the ability of traditional risk models to calculate the buffers that are needed in the financial system to absorb climate-related risks. Climate tipping points and non-linear effects limit the use of historical data. There is a tension: banks' internal models are based on historical information with typically relatively short time series; however, climate-related risks such as physical risks materialize over a very long time horizon and are likely not captured in historical data.

This puts the debate on "green risk weights" into perspective. Generally, addressing climate-related risk in supervision should be in pursuance of objectives related to the risk based prudential regulation of banks.[21] Environmental regulation and (macro-)prudential regulation of banks are distinct policy objectives, addressing environmental externalities and systemic risk externalities, respectively. Such externalities, by definition, cannot be captured by banks' internal models which are geared towards an assessment of the risks of an individual institution, not the system.

At the same time, buffers are needed in order to protect the financial system against general uncertainty. Uncertainty prevails with regard to the materialization of risks, vulnerability and exposure of the real economy and the financial system, the speed and effects of technological change, behavioral changes and, not least, policy responses. Scenario-based sensitivity analyses can help to identify potential vulnerabilities and may serve as an important tool to assess the resilience of the financial system.

Higher equity capital might be needed to address the specific nature of climate-related investments, in particular the long-term horizons and the high degree of uncertainty. Investments in the real economy require funding through debt and equity alike, and banks needs to be sufficiently capitalized to have buffers against unforeseen future contingencies.

In sum, a well-functioning financial system is crucial to contribute to the allocation of climate-related risks and the financing of innovations. In order to play this role, the financial

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[21] In a similar vein, see Carolyn Rogers, the Secretary General of the Basel Committee for Banking Supervision (BCBS) in Börsenzeitung (January 5, 2021).

system must have a sufficient degree of resilience to withstand shocks both along the policy induced transition path to an economy with net zero emissions and to physical risks. Large shocks of a global nature cannot be insured within the financial system. Ex ante insurance against the Covid-19 shock, for example, was not possible, and the stability of the financial system was contingent upon massive fiscal and monetary policy intervention in the real economy ex post.

In the context of climate change, preventive policies are thus needed to address climate-related risks sufficiently early. Macroprudential policies can complement such policies by ensuring that the financial system can play its role for society – even in times of stress and structural change.

Literature

Acemoglu, Daron, Philippe Aghion, Leonardo Bursztyn and David Hemous (2012). The Environment and Directed Technical Change. *American Economic Review* 102(1): 131–166.

Barro, Robert J. and David B. Gordon (1983). Rules, discretion and reputation in a model of monetary policy. *Journal of monetary economics* 12 (1): 101–121.

Battiston, Stefano, Aantoine Mandel, Irene Monasterolo, Franziska Schütze and Gabriele Visentin (2017). A Climate Stress-Test of the Financial System, *Nature Climate Change* 7 (4): 283–288.

Benigno, Pierpaolo (2016). The relevance or irrelevance of asset purchases programs. Remarks prepared for the Riksbank Conference "Rethinking the Central Bank's Mandate" Stockholm, June 3-4, 2016.

Berg, Florian, Julian F. Koelbel and Roberto Rigobon (2020). Aggregate confusion: the divergence of ESG ratings.

Bolton, Patrick (2021). Natural Disasters, Climate Change, and Central Bank. February Mimeo.

Bolton, Patrick, Morgan Despres, Luiz A. Pereira da Silva, Frédéric Samama and Romain Svartzman (2020). The green swan – Central banking and financial stability in the age of climate change. Bank for International Settlements. Basel.

Carare, Alina, Carlos de Resende, Andrea T. Levin and Chelsea Zhang (2021). Do Monetary Policy Frameworks Matter in Low Income Countries? National Bureau of Economic Research. NBER Working Paper 28536. Cambridge MA.

Carney, Mark (2015). Breaking the tragedy of the horizon - climate change and financial stability. Bank of England. Speech given at Lloyd's of London.

Carney, Mark (2021). Andrew Crockett Memorial Lecture: "The art of central banking in a centrifugal world". Bank for International Settlement. Basel.

Carattini, Stefano, Garth Heutel and Givi Melkadze (2021). Climate Policy, Financial Frictions, and Transition Risk. National Buerau of Economic Research (NBER). Working Paper 28525. Cambridge MA.

Cecchetti, Stephen G. and Paul Tucker (2015). Is there macroprudential policy without international cooperation? Asia Economic Policy Conference. *Policy Challenges in a Diverging Global Economy*: 79-110.

Coase, Ronald H. (1960) The problem of social cost. *The Journal of Law and Economics 3:1-44.*

Cochrane, John (2021). Testimony of John H. Cochrane to US Senate Committee on Banking, Housing, and Urban Affairs. https://www.banking.senate.gov/imo/media/doc/Cochrane%20Testimony%203-18-21.pdf

de Guindos, Luis (2020). Capital markets union: the role of equity markets and sustainable finance. Contribution by the Vice-President of the ECB on the occasion of the

publication of the ECB report on “Financial integration and structure in the euro area”, Frankfurt a.M.

De Haas, Ralph and Alexander Popov (2019). Finance and decarbonisation: why equity markets do it better. ECB Research Bulletin. Frankfurt a.M.

Deutsche Bundesbank (2019). Financial Stability Review 2019. Frankfurt a.M.

Dietz, Simon, Alex Bowen, Charlie Dixon and Philip Gradwell (2016). Climate Value at Risk’ of global financial assets. Nature Climate Change. London.

Edge, Rochelle M. and J. Nellie Liang (2020). Financial Stability Governance and Basel III Macroprudential Capital Buffers. Hutchins Center Working Paper 56. Brookings. Washington DC.

Edenhofer, Ottmar, Max Franks and Matthias Kalkuhl (2021). Pigou in the 21st Century: a tribute on the occasion of the 100th anniversary of the publication of The Economics of Welfare. *International Tax and Public Finance*.

Edenhofer, Ottmar and Michael Jakob (2019). *Klimapolitik: Ziele, Konflikte, Lösungen*. C.H. Beck.

Frank, Robert H. (2020). *Under the Influence – Putting Peer Pressure to Work*. Princeton University Press.

Financial Stability Board (FSB) (2020), The implications of climate change for financial stability, Retrieved Dec 21, https://www.fsb.org/2020/11/the-implications-of-climate-change-for-financial-stability/

Fücks, Ralf (2013). *Intelligent wachsen: Die grüne Revolution.* Hanser.

Fücks, Ralf and Thomas Köhler (eds.) (2019). *Soziale Marktwirtschaft ökologisch erneuern: Ökologische Innovationen, wirtschaftliche Chancen und soziale Teilhabe in Zeiten des Klimawandels*. Zentrum Liberale Moderne und Konrad Adenauer Stiftung.

Fuest, Clemens (2020). Vorteile der Arbeitsteilung gelten auch in der Wirtschaftspolitik: Der Green New Deal. IFO Standpunkte 221. München.

Furukawa, Kakuho, Hibiki Ichiue and Noriyuki Shiraki (2020). How Does Climate Change Interact with the Financial System? A Survey. Bank of Japan. Working Paper. No.20-E-8. Tokio

G30 (2020). Mainstreaming the transition to a net-zero economy, Group of Thirty Report. Washington DC.

Giglio, Stefano, Bryan T. Kelly and Johannes Stroebel (2020), Climate Finance, National Bureau of Economic Research. NBER Working Papers 28226. Cambridge MA.

Helm, Dieter, Cameron Hepburn and Richard Mash (2003), Credible carbon policy, *Oxford Review of Economic Policy*, Vol. 19, pp. 438-450.

Hepburn, Cameron, Nicholas Stern and Joseph E. Stiglitz (2020). Carbon pricing. *European Economic Review 1*27.

Holz, Franziska, Ivo Valentin Kafemann, Oliver Sartor, Tim Scherwath and Thomas Spencer (2018). What Does “Peak Coal” Mean for International Coal Exporters? A Global Modelling Analysis on the Future of the International Steam Coal Market. Paris and

London: Institute for Sustainable Development and International Relations and Climate Strategies.

Huxham, Mattew, Muhammed Anwar and David Nelson (2019). Understanding the Impact of a Low Carbon Transition on South Africa. San Francisco, CA: Climate Policy Initiative.

Intergovernmental Panel on Climate Change (IPCC) (2018). Global Warming of 1.5°C: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels Masson-Delmotte, Valerie, Panmao Zhai, Hans-Otto Pörtner, Debra Roberts, Jim Skea, Priyardarshi R. Shukla, Anna Pirani, Wilfran Moufouma-Okia, Clotilde Péan, Roz Pidcock, Sarah Connors, J.B.Robin Matthews, Yang Chen, Xiao Zhou, Melissa I. Gomis, Elisabeth Lonnoy, Tom Maycock, Melinda Tignor and Tim Waterfield (eds.)

International Monetary Fund (IMF) and Organisation for Economic Co-operation and Development (OECD) (2021). Tax Policy and Climate Change. IMF/OECD Report for the G20 Finance Ministers and Central Bank Governors. April 2021. Italy. www.oecd.org/tax/tax-policy/imf-oecd-g20-report-tax-policy-and-climate-change.htm.

Kolstad, Charles D. (2011). *Intermediate Environmental Economics*. Oxford University Press.

Kydland, Finn E. and Edward C. Prescott (1977). Rules rather than discretion: The inconsistency of optimal plans. *Journal of Political Economy* 85 (3): 473–491.

McGlade, Christoph and Paul Ekins (2015). The geographical distribution of fossil fuels unused when limiting global warming to 2 C. *Nature*, *517*(7533), 187-190.

Network for Greening the Financial System (NGFS) (2020a). NGFS Climate Scenarios for central banks and supervisors. Paris.

Network for Greening the Financial System (NGFS) (2020b). Survey on monetary policy operations and climate change: key lessons for further analyses. Technical Document. Paris.

Network for Greening the Financial System (NGFS) (2021). Progress report on bridging data gaps. Technical document. Paris.

Ostrom, Elinor (1990). *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge, UK: Cambridge University Press.

Pastor, Lubos, Robert F. Stambaugh and Lucian A. Taylor (2020). Sustainable investing in equilibrium. *Forthcoming Journal of Financial Economics*

Phelps, Edmund S., Sidney G. Winter Jr., Armen A. Alchian, John P. Gould, Charles C. Holt, Donald F. Gordon, Dale T. Mortensen, Allan Hynes, Donald A. Nichols, Robert E. Lucas Jr., Paul J. Taubman, Leonard A. Rapping, G.C. Archibald and Maurice Wilkinson (1969). *Microeconomic Foundations of Employment and Inflation Theory.* NewYork: Norton.

Pigou, Arthur C. (1920). *The economics of welfare*. MacMillan. London.

Reinhart, Carmen M. and Kenneth S. Rogoff (2009). *This Time Is Different: Eight Centuries of Financial Folly.* Princeton University Press.

Reis, Ricardo (2013). The mystique surrounding the central bank's balance sheet, applied to the European crisis. National Bureau of Economic Research (NBER). Working Paper 18730. Cambridge MA.

Rogoff, Kenneth S. (1985). The optimal degree of commitment to an intermediate monetary target. *The Quarterly Journal of Economics* 403: 1169-1189.

Sachverständigenrat zur Begutachtung der wirtschaftlichen Entwicklung (2019). *Aufbruch zu einer neuen Klimapolitik.* Wiesbaden.

Schmidt, Klaus M. and Fabian Herweg (2021). Prices versus Quantities with Morally Concerned Consumers. University of Munich. Mimeo.

Sustainable Finance Beirat (2021). Shifting the Trillions – Ein nachhaltiges Finanzsystem für die Große Transformation. Berlin.

Tirole, Jean (2019). Institutional and economic challenges for central banking. In: Monetary Policy: the challenges ahead. European Central Bank. Colloquium in Honour of Benoît Cœuré held on 17-18 December 2019. Frankfurt a.M.

Tucker, Paul (2016). The Design and Governance of Financial Stability Regimes Common-resource Problem That Challenges Technical Know-How, Democratic Accountability and International Coordination. Centre for International Governance Innovation (CIGI). Essays on International Finance. Volume 3. September.

Tucker, Paul (2018). *Unelected Power: The Quest for Legitimacy and the Regulatory State*. Princeton University Press.

Weidmann, Jens (2020). Welche Rolle sollten Notenbanken im Kampf gegen den Klimawandel spielen? Speech on the occasion of the conference „Green Banking and Green Central Banking: What are the right concepts?“ Goethe-Universität Frankfurt a. M., 25 January 2020.

Weitzman, Martin L. (1974). Prices vs. Quantities. *The Review of Economic Studies.* 41 (4): 477-491.

Wissenschaftlicher Beirat beim Bundesministerium der Finanzen (BMF). Grüne Finanzierung und Grüne Staatsanleihen – Geeignete Instrumente für eine wirksame Umweltpolitik? Gutachten 1/2021. Berlin