The potential contribution of central banks to green finance

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Summary: Central banks and financial supervisors approach 'green finance' mostly to preserve macroeconomic and financial stability according to their mandates. Obviously, climate change poses severe risks to households, firms and their financial intermediaries. These risks tend to be correlated and their scope goes beyond historical evidence, therefore their impact on the financial system is difficult to model. On the other hand, the planned decarbonization of the global economy creates enormous investment opportunities. Central banks and supervisors play a role in safeguarding the financial system's smooth transformation from funding old, brown industries to funding a new green economy. The 'Network for Greening the Financial System' facilitates an exchange of experience and ideas among central banks and financial supervisors; we present some of their findings. While central banks can and should contribute to making the economy and the financial system more sustainable, they can only complement, but not substitute for, decisive political action by governments.

Zusammenfassung: Zentralbanken und Finanzaufsichtsbehörden haben beim Thema „Green Finance" vor allem die makroökonomische und finanzielle Stabilität im Sinne ihrer Mandate im Blickpunkt. Denn einerseits birgt der Klimawandel erhebliche Risiken für Haushalte, Unternehmen und deren Finanzintermediäre. Diese Risiken sind in der Regel korreliert und ihr Umfang geht über historische Erfahrungswerte hinaus. Daher sind ihre Auswirkungen auf das Finanzsystem schwer zu modellieren. Andererseits schafft die geplante Dekarbonisierung der Weltwirtschaft enorme Investitionsmöglichkeiten. Zentralbanken und Aufsichtsbehörden können zur reibungslosen Umstellung des Finanzsystems zur Finanzierung einer neuen „grünen" Wirtschaft statt alter, „brauner" Industrien beitragen. Das „Network for Greening the Financial System" erleichtert den Erfahrungs- und Ideenaustausch zwischen Zentralbanken und Finanzaufsichtsbehörden. Wir präsentieren hier einige ihrer Erkenntnisse. Trotz ihrer wichtigen Rolle bei der nachhaltigen Gestaltung der Wirtschaft und des Finanzsystems können Zentralbanken entschlossenes politisches Handeln der Regierungen nur ergänzen, nicht jedoch ersetzen.

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1 Introduction

Climate change is the source of significant structural changes that affect the economic and financial system. These structural changes pose severe risks to financial stability, and therefore climate change has gained the attention of central banks and supervisors. One of the first declarations of this new interest of central bankers in the topic was a speech by the Governor of the Bank of Finland (Liikanen, 2008), who raised concerns about the climate-related volatility of inflation and inflation expectations. After the global financial crisis, the Governor of the Bank of England (Carney, 2015) characterized the lack of adequate policy action as the "tragedy of the horizons". This refers to the problem of time inconsistency, which is well known to central bankers from the conduct of monetary policy, but which also affects climate policies. The anthropogenic emissions of CO_2 and other greenhouse gases (GHG) and their harmful effects on the global climate do not coincide in time. The IPCC (2018) special report concludes that even if effective actions that would drastically reduce CO_2 emissions to net zero by the 2050s were taken now, the CO_2 concentration in the atmosphere and, accordingly, global temperatures would merely stabilize at roughly the current level until the end of the century. In contrast, if emissions are allowed to rise along a business-as-usual path, they could cause temperatures to increase by almost another 5 °C until 2100.

The costs of climate policy inaction do not accrue instantaneously, but are delayed by years, probably decades. Most policymakers do not wish to burden the current electorate with higher gasoline prices and expensive regulations in the interest of future generations as this might dampen their present chances of being elected[1]. Even if we all agreed that a plan to decarbonize was socially and economically desirable, it would be in the self-interest of politicians to deviate from this plan in the short run as long as voters seem to sufficiently discount their future disutility (and that of their offspring). This inhibition reduces the probability of effective policy changes in the very near future, and this, in turn, increases the probability that the risks we describe will materialize.

The Stern Report (2006) describes climate change as the historically biggest market failure because it exhibits negative externalities that are distributed globally and persistent for centuries. An immediate drastic reduction of CO_2 emissions would be much cheaper in the long run than a continuation of current policies. At the heart of effective mitigation policies is a price for carbon that reflects its social costs; but these policies are subject to time inconsistency as described above. According to the Stern report, the cost of unchecked global warming could equal 5% to 20% of global GDP annually, while the cost of an effective avoidance strategy would be limited to 1% of global GDP annually. In addition, actions against climate change also create business opportunities for new markets in low-carbon industries, which help to decouple economic growth from greenhouse gas emissions.

In the Paris Agreement of 2015, the majority of countries in the United Nations have subscribed to the joint aim of countering the threatening global climate catastrophe by keeping the global temperature rise this century well below 2 degrees Celsius. To reach this aim the global economy needs to reorient itself toward a sustainable generation and use of energy, which will require massive investment. According to estimates by the European Commission, Europe alone will need to spend additional annual funds of EUR 180 billion, e. g. investment in infrastructure for transport and

1 The most obvious remedy for intergenerational burden sharing, an increase in public debt, has lost much of its political appeal in the last financial crisis.

energy and technological research. Obviously, a large part of green investments will need to come from private sources.

Green finance aims to achieve a greening of the financial system by channeling financial flows toward investments that are environmentally friendly and will limit the effects of climate change wherever possible. Examples of green finance products range from loans for roof solar collectors to "green bonds" used to finance wind farms, for example, or an investment in sustainable mutual funds. Currently, green investments are still a niche market, but they are growing very fast. Studies document that green investments generate similar yields as comparable mainstream investments (Giese and Lee, 2019).

The newly established Network for Greening the Financial System (NGFS) facilitates central banks' and supervisors' exchange of experience and ideas in three areas: microprudential supervision, macroprudential analysis and measures to scale up green finance. In its recent Comprehensive Report, the NGFS (2019) calls for action and presents four recommendations for central banks and supervisors: (1) integrating climate-related risks into financial stability monitoring and micro-supervision, (2) integrating sustainability factors into their own portfolio management, (3) bridging data gaps, and (4) building awareness and intellectual capacity and encouraging technical assistance and knowledge sharing.

Much of the debate on the compatibility of central banks' engagement in climate issues with their mandate has been resolved. "Climate-related risks are a source of financial risk and it therefore falls squarely within the mandates of central banks and supervisors to ensure the financial system is resilient to these risks." (NGFS, 2019: 1). At a minimum, central banks should monitor and analyze the effects of climate change on the transmission of monetary policy and financial stability (Mersch, 2018). Furthermore, they could actively support the transition to a low-carbon economy "by helping to define the rules of the game by acting accordingly, without prejudice to price stability." (Cœuré, 2018). Hence, we see that all three typical objectives of central banks – i. e. price stability, financial stability and overall economic policy – are concerned.

However, there are limits to what central banks can do. Governments have a leadership role in providing a clear transition path on which households and firms could build their investment decisions. Legislators could also help to transform the financial infrastructure, just as the European Commission's Action Plan does.

The remainder of this article is structured as follows: The next section specifies the different risks to financial stability that can be the consequences of climate change and briefly discusses policy actions. The next section presents some of the market opportunities for financial intermediaries that result from climate change mitigation and adaption and asks how central banks could contribute to the development of green finance markets. Then we lay out the monetary policy options for safeguarding against climate-related risks, and how they complement existing monetary policy frameworks. The concluding remarks summarize our contribution and present some ongoing initiatives among central banks and financial supervisors that aim at integrating climate change into the field of monetary policy and supervision.

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2 The economic and financial stability risks of climate change

In this section, we specify macroeconomic and financial risks according to their origins, and we outline their transmission channels to the economy and financial markets. We follow Carney (2015) and Batten et al. (2016) by clustering these risks into physical risks, transition risks and liability risks, all of which have distinctive economic and financial implications. Finally, we present some initiatives and measures to improve the management of these risks.

When talking about risks, we do not reflect upon the distinction of risk and uncertainty by Frank Knight. According to Knight (1921), risk refers to unknown future events that follow a known probability distribution and whose occurrence therefore can be estimated, whereas uncertainty describes situations that are unique in nature, so we cannot estimate their probabilities. Risk can be measured and calculated, uncertainty cannot. In this sense, climate change and its consequences are rather uncertain as the atmospheric concentration of CO_2 and other GHGs is historically unprecedented in the last 800,000 years (IPCC, 2014). The scenario of an increase in global average temperatures by 5 °C would bring about a unique environment that humankind has never experienced before. Hence, we can only guess whether the related damages would increase linearly or exponentially, or how they will be distributed across regions and sectors.

2.1 Physical risks

Physical risks refer to the effects of rising temperatures and an increasing number of extreme weather events like droughts and floods or rising sea levels caused by climate change. These risks can affect both the supply and the demand side of the economy. An increase in global warming will impact on labor supply in many countries because higher temperatures can erode public health and productive working conditions in firms. The increase of extreme weather events like heavy storms will have a similar effect. Global warming can also lead to a faster corrosion of machines and buildings, thereby speeding up the depreciation of the capital stock. The combined negative effects on labor and capital reduce future output as climate change proceeds. With respect to the price stability, the dire consequences of climate change on agriculture are likely to cause more volatility in food prices.

Next to these impacts on prices and output levels, there is also a negative effect on output growth stemming from physical risks, as emphasized by Bowen and Dietz (2016). The immediate damages on the capital stock of firms will redirect more capital investment into repair and replacement, and proportionally less funds can be allocated to research and innovation, the drivers of productivity and growth. Future lower capital productivity would imply a lower equilibrium interest rate, which has direct repercussions for monetary policy. The cost of climate change in an endogenous growth framework has been analyzed by Acemoglu et al. (2012), who conclude that an optimal policy response consists of a combination of carbon taxes and subsidies for the development of new green technologies.

On the macroeconomic impacts of physical risks, Mittnik et al. (2019) present a multi-phase dynamic macro model which endogenizes the materialization of physical risks as the CO_2 emissions affect the disaster vulnerability. While public and private debt levels increase in the aftermath of a disaster, the capital stock may even decline as rising risk premia are causing the surge in debt and the disaster wipes out some capital. At the same time, credit constraints may also slow down the

necessary reallocation of capital after an extreme weather event has hit the economy, which may call for some policy action by the monetary authorities.

The regional distribution of these effects is uncertain, and some places might even benefit from a warmer climate. Elderson (2018) gives the example of thriving vineyards in the Netherlands. But globally, the findings of integrated assessment models of climate change show that the consequences will be significantly negative; for an overview, see Nordhaus (2016). But even if the beneficiaries of climate change would gain so much that they could fully compensate the losers, this would be very unlikely to happen as positive and negative effects will most probably materialize in regions that are distant from each other and not under the same government, which would be a necessary condition for enacting such a compensatory transfer mechanism.

On the demand side, increasing expenditures for repair and replacement will ceteris paribus reduce investment on and consumption demand for other goods. Uncertainty will in general likely cause subdued or delayed investment spending by firms. If households are confronted with more extreme weather events, they might increase their precautionary savings, which depresses private consumption in general. It is worth noting that insurance can distribute the financial burden of a damage event, but the economic cost of the damage does not go away. Hence, precautionary savings of households and firms might also take the form of higher insurance premia.

2.2 Transition risks

Almost all governments agreed at the Paris climate change conference in 2015 to limit global warming to well below 2 °C compared to pre-industrial levels; this goal defines clear limits for future emissions. The transition from the current economic system to a decarbonized economy is inevitable, but it bears risks, too. As decarbonization requires some major changes in the current modes of production, the transition should start rather sooner than later to be less disruptive, while some disruption is almost certainly unavoidable. The disruption will differ from industry to industry, and, as Schoenmaker (2019) shows, even intra-industry differences in the exposure to transition risks are quite significant.

The negative externalities of CO_2 emissions prevent the functioning of a market solution for decarbonization, hence, effective policy actions are needed. Transition risks materialize when regulatory changes, additional taxes or technological innovations severely alter the expected future cash flows from productive assets, which can eventually turn them into stranded assets. Regulation and taxation can incentivize firms to divest from carbon-intensive assets and thereby change the emission path of the economy. If this divestment happens abruptly and system-wide, financial stability might suffer. However, political considerations might delay the needed upfront policy actions, and the later regulatory change is implemented, the larger must be its impact so that it can trigger sufficient market reactions to incentivize effective resource allocation away from fossil assets. A larger impact is often more disruptive and poses a greater risk to financial stability.

When regulatory reforms or new taxes change relative prices in favor of green assets, firms are not only incentivized to divest from brown assets, they are also more likely to fund research in carbon-free innovations. If these innovations yield marketable products or processes, incumbents might be replaced. According to NGFS (2018), for some industries (e. g. aviation) it might be rather difficult to find carbon-free technologies and, therefore, their production is likely to be scaled down significantly, which might create more financial distress for their owners and creditors.

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Whereas technological innovations are almost by definition hard to foresee, we have a good idea of which regulatory changes are warranted. To change the relative prices of carbon-intensive and carbon-free assets, governments could either charge a carbon tax, impose a mechanism for emission trading, subsidize green investment or indirectly change the cost structure via command-and-control regulation. A recent initiative by leading U.S. economists[2] proposed the introduction of a carbon tax which should be raised each year until emission reductions goals are met. The revenues from this tax should be returned directly to U.S. citizens so they would benefit from a “carbon dividend,” which should improve public acceptance of the new tax. The statement also proposes the introduction of a border carbon adjustment system which functions like a tariff on carbon-intensive imports and would trigger some transition risks in other countries.[3]

2.3 Liability risks

Despite all pledges to limit climate change, we are very likely to experience some of the negative effects described above. In accordance with the “polluter pays” principle, entities that have been negatively affected by climate change could seek compensation from those who were causing the damage and thereby at least partially internalize negative externalities. Of course, it is difficult to establish a direct link between cause and effect that would allow a claimant to sue for compensation because CO_2 emitters contribute to climate change in general and not to a particular drought or storm. And as climate change is a global phenomenon, the causing parties will often be located in a different jurisdiction than the affected parties, which complicates the arbitration process.

From a financial stability perspective, two issues are pertinent here. First, given the increasing probability that physical risks will materialize over the coming decades, insurance companies may face an increasing number of claims. As all these events are caused by climate change, they are correlated, which might not be fully reflected in the calculations of the insurance industry. Therefore, the effects of an increase in natural disasters due to climate change have been incorporated in EIOPA’s insurance stress tests (EIOPA, 2018). Severe unexpected losses could propagate via reinsurance companies and other interlinkages in the financial system.

Secondly, it is difficult for investors at the current stage to evaluate the potential exposure of an asset to climate change as past data do not contain the expected increase of correlated risk. Many companies do not disclose their exposure to climate-related risks even if they are aware of their existence. Nevertheless, some firms have started to offer so-called “green bonds” and other investment vehicles which claim to be climate-neutral. In the absence of an agreed methodology to classify the effects of economic activities on the climate, investors and supervisors are unable to verify these claims.

2.4 Prudential policies to tackle climate-related financial risks

In its latest report, the NGSF (2019) recommends integrating these risks into the prudential supervision framework. A necessary precondition for assessing exposure to climate-related risks is the transparent and reliable disclosure of relevant information. For the time being, private ini-

2 Interestingly, the statement was signed by all former Federal Reserve presidents, next to several Nobel laureates and former treasury secretaries. https://www.econstatement.org/.

3 For more on the economics of border carbon adjustment systems, see McLure (2014).

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tiatives coexist with official regulatory proposals aiming for more transparency of climate-related business risks.

The Financial Stability Board has established the Task Force on Climate-related Financial Disclosures (TCFD) in 2015 under the chair of Michael Bloomberg to develop voluntary, consistent climate-related financial risk disclosures for well-informed investment, lending, and insurance underwriting decisions. The TCFD developed a framework for companies to disclose their risks more effectively in existing reports. This framework was published in 2017 and refers to the application of metrics and targets to measure climate-related risks, their incorporation in firms' risk management systems, the strategic control of these risks and the firm-specific governance around climate-related risks. As the TCFD is a voluntary initiative, its recommendations are not binding on their members. In a recent status report (TCFD, 2018), the results of a review of disclosure practices among more than 1,700 firms worldwide were summarized, showing that only few companies have indeed incorporated climate-related risks in their governance or their risks management practices so far, but clearly more have already developed or applied metrics and tackled strategic issues.

In March 2018, the European Commission adopted an action plan on sustainable finance which aims to make financial risks stemming from climate change more manageable. The action plan contains 10 actions, the first of which is to establish an EU classification system for sustainable economic activities. This taxonomy will be compiled by a technical expert group on sustainable finance and should identify activities which contribute positively to climate change mitigation and adaptation. This should allow financial market participants to reorient their investments towards a more sustainable economy and thereby reduce climate-related risk. However, from a risk managing perspective, it would be useful to classify economic activities which are more prone to climate-related risks as described above.

Financial corporations can already now attempt to quantify the climate-related risks they have on their balance sheets. For example, Battiston and Monasterolo (2018) have carried out a carbon risk assessment of the OeNB's non-monetary portfolio by pricing climate transition risk in individual contracts (i. e. equities, sovereign bonds, corporate bonds). All assets are benchmarked according to their contribution to GHG emissions, and then the transition to a 2 °C scenario is modeled as a negative shock to the future value added of the carbon-intensive sectors. As a result, each asset is attached with a positive or negative risk spread that informs investors about the likely impact of transition risks on their portfolio. Given the expectable transition risks of climate change, such an assessment is a valuable instrument for institutional investors. From a systemic viewpoint, it would be desirable to have a model for the aggregate financial sector that allows analyzing the feedback loops from climate change to financial intermediaries and their reactions to each other because the correlated response of many intermediaries to the same shock might aggravate its adversity.

The Commission's action plan also suggests extending the macroprudential toolbox to deal with climate risks. Action 8 proposes to explore the feasibility of the inclusion of a so-called green-supporting factor in the calibration of capital requirements of banks to safeguard financial stability. Given the importance of bank funding for European companies, this could incentivize firms to invest more in sustainable technologies. However, the risk perspective would rather suggest penalizing the funding of activities that are detrimental to the climate objectives that have been agreed in Paris. It is probably more difficult to assess in advance the risk profile of new green technologies than the contributions of existing brown technologies to climate change, and a green-supporting

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factor would not mitigate the negative effects for banks when physical or transition risks materialize. In its 2017 interim report, the EU High-Level Expert Group on Sustainable Finance also seems to prefer the idea of a brown-penalizing factor to a green-supporting factor.

However, before any of these prudential instruments can be applied, a reliable classification of economic activities with respect to their climate impact is warranted. So far, there is no clear evidence that green investment is safer than brown investment. One notable exception is China, where green loans have a lower non-performing loan (NPL) ratio than average loans. Consequently, China has already lowered its capital requirements to encourage green investment. More recently, the EU has adopted modest regulatory changes in this direction, which are, however, limited to publicly organized infrastructure investment in its implementation legislation of Basel III (CRR II).

3 The market opportunity perspective

Taking and managing calculated risk is at the core of any financial business. Tackling the causes and consequences of climate change (i.e. mitigation and adaptation) presents possibilities for technological and organizational innovation, which generates competitive advantage for entrepreneurs. The global transition to a low-carbon economy could stimulate innovations that generate dynamic prosperity in the sense of Schumpeter's thesis on "creative destruction" (Mooslechner, 2016). And while the financial industry has shortcomings in dealing with common risks, given its inherent short-termism, myopia, and its tendency to overshoot, it can claim to optimally price diversifiable risk. The imperative decarbonization of the economy with its huge investment challenge is likely to rely on the capability of financial markets to re-allocate resources. But how can central banks and supervisors facilitate this conversion of finance? On the one hand, they should create framework conditions that help the relevant market segments to grow out of infancy. On the other hand, they can provide a best-practice example in their own activities and urge regulators to limit paralyzing uncertainty.

3.1 Mainstreaming green financial markets

The transition to a low-carbon economy agreed in Paris requires tremendous amounts of investment. Cleaning the global energy system is estimated to entail the mobilization of around USD 2.4 trillion per year until 2035, which represents about 2.5% of the world GDP (IPCC, 2018). The European Commission (2018) projects the equivalent for the EU to be EUR 180 billion per year until 2030 – slightly more than 1% of its GDP. Assuming constraints and a reluctance to fund this transition with public money, the private sector must play an important part. Many green projects, however, lack the necessary scale, short-term returns and manageable risk. Making these projects bankable calls for an appropriate framework of cost-efficient regulations and economic instruments. Various central banks have joined forces with other stakeholders including supervisors, regulators, market players, as well as investment project originators to raise the attractiveness of low-carbon investments. While better knowledge of climate risks and opportunities in investment portfolios through disclosure requirements increases cost transparency, government guarantees may kick-start specific projects via lower funding costs. External reviews and certifications increase investors' confidence and provide the necessary credibility, facilitating market growth and innovations.

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For instance, since the first issuance in 2007, the green bond market has benefitted from Green Bond Principles[4] and has been expanding rapidly to an issuance volume of USD 180 billion in 2018. Although noticeable oversubscription implies high potential, green bonds represent just a tiny fraction of the entire global bond market. Hence, scaling up green finance from its niche to mainstream will need huge efforts. Carbon emissions trading is already one of the fastest-growing financial market segments. In 2018, the value of traded global markets for carbon dioxide trading more than tripled year on year to a record high of EUR 144 billion.[5] To be sure, much of the increase was due to an anticipated removal of surplus permits from the EU emission trading system (ETS). Regardless of its cyclical behavior and structural volatility, carbon emission trading is likely to remain very dynamic. Currently, only 8% of global CO_2 emissions are covered by ETS, and the carbon price is in most cases lower than USD 20 per ton of CO2 (IPAC, 2019), far away from the price of USD 40 to 80 recommended by Stern and Stiglitz (2017), which only marks the starting point of a constantly increasing path typical to cap-and-trade regimes.

Recognizing its responsibility in making our economy sustainable, the financial industry must integrate environmental considerations into all aspects of its operations. Instead of approaching climate change merely through the lens of corporate social responsibility (CSR), it should tackle the challenge via risk and opportunity management. As the main financial intermediary, the banking sector has an essential role in providing timely, practical and cost-effective solutions to climate change. With the millennial generation accumulating more wealth, the demand for climate-friendly products and services will grow, opening up opportunities for new markets. Many commercial banks are already responding to these requirements with new strategies: measures include CO_2 neutrality objectives, clear accountability at the board level, working group set-up, regular eco-reporting or climate-neutral procurement. In addition, some are already targeting climate-specific objectives in their lending policies, engaging in renewable energy markets and offering climate risk management products. Individual customers are offered climate-specific funds, green mortgages or green car loans. A few central banks, regulators and local authorities have introduced incentives for banks to increase green lending as well as for issuers to issue green bonds.

3.2 Leading by example

Central banks can aim at best practice in environmental management, including energy and water efficiency, recycling and waste reduction. They also can seek to form business relations with customers, partners, suppliers and subcontractors who comply with similarly high environmental standards. More and more central banks develop corporate environmental strategies. They commit themselves to continuously improving their environmental performance by adopting environmental guidelines and targets, e. g. reducing their carbon footprint, undergoing eco audits, committing themselves to sustainability, ecological purchasing, employee training, resource conservation and waste prevention. The OeNB, for instance, has halved its energy consumption per employee since its first reporting in 2001 and pledged to aim at carbon neutrality.

Some central banks are also starting to scale up green finance by accounting for climate and environment-related factors in their investment strategies. They have incorporated specific sus-

4 https://www.icmagroup.org/green-social-and-sustainability-bonds/green-bond-principles-gbp/.

5 https://www.reuters.com/article/us-global-carbontrading-report-idUSKCN1PA27H.

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tainability risk criteria in their non-monetary policy reserve management. Reflecting international standards, the OeNB, for instance, initially defined exclusion criteria to prevent reputation risks. Then, as of 2011, external asset managers that make investments for the OeNB have had to commit themselves to the UN Principles for Responsible Investment. Later, sustainability aspects in portfolio decisions were covered by an extensive application of Environmental, Social and Governance (ESG) criteria. More recently, the OeNB placed an investment order with an ESG filter in selected asset classes and awarded several external investment mandates tied to ESG benchmarks and ESG criteria. Based on this experience and in line with best practices emerging in the market, the OeNB plans to expand the application of such criteria to further asset classes.

4 Possible contributions of monetary policy

While persistent climate-induced natural disasters and extreme weather events endanger financial stability, climatic disruption also affects monetary policy and its potential to respond to different kinds of shocks. A new strand of literature investigates which monetary policy rule is best suited in a climate-disrupted world (McKibbin et al., 2017). Basically, as demand shocks push output and inflation in the same direction, they are, if correctly identified, easily manageable. But climate-related shocks are typically negative supply shocks that push up inflation and reduce output. If both variables of the central bank's reaction function, inflation and output, move in opposite directions, this poses a dilemma for the central bank as it has to decide whether priority should be given to output or to inflation stabilization. Thus, for example, the economy's persistent dependence on fossil fuels such as petroleum and natural gas, the elevated volatility in oil and gas prices and the difficulty in forecasting them have posed severe challenges for the conduct of monetary policy already for some decades. Usually, central banks tend to accommodate supply shocks, in particular if they are identified as being of temporary nature with negligible effects for the medium-term inflation outlook. But it seems that climate change is a trend rather than a cyclical phenomenon making the incidents of climate-related supply shocks more frequent and potentially overlapping; this, in turn, makes the assessment of incoming data more difficult and the decision about the optimal monetary policy response much more complicated. For example, given continued and growing demand for fossil fuels and assuming successively depleting oil reserves, more persistent oil price shocks cannot be ruled out.

Hence, mitigating climate change risks, transforming the energy system towards regenerative energy sources and increasing energy efficiency should facilitate the conduct of monetary policy. At the same time, this certainly poses challenges during the transition phase as well. But monetary policy itself can support the transformation process. In principle, a central bank has a fairly large set of tools at its disposal to impact the creation and allocation of credit. This also involves allocating finance to any activities that bolster the transformation towards a low carbon economy, a process monetary policy can support through various means, depending on the prevailing operational framework, which differs widely across the world's central banks: 1) via monetary policy portfolios (quantitative easing), 2) via targeting refinancing operations contingent on private credit allocation towards low-carbon activities (credit easing), and 3) via adapted eligibility criteria for collateral in monetary refinancing operations.

4.1 Quantitative easing

The launch of substantial quantitative easing (QE) programs has sparked an academic and policy debate about the environmental implications of the choice of assets purchased under such programs[6]. By purchasing financial assets, such as sovereign or supranational bonds, asset-backed securities, covered bonds, corporate bonds or equities, the yields (prices) of those assets decline (rise), thereby reducing financing costs, encouraging additional debt issuance, increasing lending and spurring economic growth. When designing their asset purchase programs, several central banks, including the ECB, aimed to ensure market neutrality in order to minimize the impact on relative prices within the eligible universe and unintended side effects on market functioning, such as distortions in market liquidity (Hammermann et al., 2019). The ECB, for instance, purchased and is still reinvesting maturing sovereign bonds taking into account the maturity distribution in the market. Moreover, it bought and is reinvesting maturing corporate bonds following the sectoral weights of the bond markets. Other central banks followed more targeted approaches in QE. For example, in its initial round of quantitative easing (2008–2010), the U.S. Federal Reserve predominantly purchased mortgage-backed securities in order to revive the distressed housing market and encourage increased lending to households.

In theory, given imperfect substitutability between financial assets purchased under QE and base money created in this process, the working of the portfolio rebalancing channel should safeguard that not only the longer-term yields of the assets directly purchased by the central bank, but also the yields of all asset classes across the board decline. This is because investors rebalance their portfolios by purchasing assets with similar characteristics to replace those QE securities they sell to the central bank. If this channel works efficiently, the choice of the assets purchased by the central bank should be irrelevant because the price impact of the specific purchases should trickle down to all financial assets. From this perspective, the purchases of non-financial corporate bonds, such as those under the corporate sector purchase programme (CSPP) of the ECB, even if they might increase the climate risk of the central bank's balance sheet[7], should not skew overall investment towards high-carbon sector assets in the economies. However, empirical evidence of the portfolio rebalancing effects of asset purchase programmes is mixed and points to somewhat stronger price effects for financial assets directly purchased by the central bank and for asset categories that are eligible for central bank purchases (Bua and Dunne, 2017; Goldstein et al., 2018; Rogers et al., 2014). It follows that the choice of the asset class as well as of the asset category (low- versus high-carbon industry bonds) within an asset class (corporate bonds) matters and has a selective effect on the economy. One concern is that a high share of carbon-intensive assets in monetary policy's portfolio could contribute to self-perpetuating inertia created by fossil fuel-based production schemes (carbon lock-in) that inhibits efforts to introduce alternative energy infrastructure (Unruh, 2000). No doubt, non-financial corporate bonds, purchased under QE programs, exhibit a carbon-intense bias – meaning a larger proportion of purchases of high-carbon bonds, such as utility firms, than their proportional contribution to gross value added (Matikainen et al., 2017).[8] But in some

6 See for example de Grauwe (2019).

7 Those assets have been found to be disproportionately carbon-intensive by Matikainen et al. (2017).

8 The Bank of Japan stands out with its significant purchases of equities through exchange traded funds. As reported by Matikainen (2018), the Bank of Japan's equity portfolio is somewhat less carbon intensive than the corporate bond portfolio of the ECB and the Bank of England.

cases, the bias towards high-carbon corporate bond purchases mainly reflects the fact that the non-financial corporate bond market is disproportionally skewed towards the high-carbon sector because of the relative good ratings of the larger high-carbon firms (i. e. automotive, fossil fuels and utility companies). Low-carbon firms are often too small to issue corporate bonds. While still accounting for only 1 % of overall bond supply denominated in euro, the net issuance of green bonds in the euro area has nonetheless increased tenfold since 2013 (De Santis et al., 2018). Extrapolating these dynamics into the future would require a disproportionately higher share of purchases of low-carbon corporate bonds.

While the carbon intensity of the central bank's corporate bond portfolio has attracted a great deal of attention because it can be assessed directly, other assets of monetary policy portfolios are also relevant (Schoenmaker, 2019). The carbon intensity of bank bonds can be evaluated through the carbon intensity of a bank's total loan portfolio. In the case of asset-backed securities, a look-through approach can be applied that evaluates the carbon-intensity of the underlying assets. In the case of government bonds (including those of development banks), which typically make up by far the largest share of assets being purchased within QE programs, the environmental impact can be assessed based on government commitment to support low-carbon activities. Recently, governments have started to issue sovereign green bonds, among them Belgium, France, Ireland, Lithuania and the Netherlands.[9] One particular proposal is that central banks purchase green bonds issued by development banks that use the funds to finance environmental investments at a large scale (De Grauwe, 2019). The fact that in this case central banks do not directly interfere with credit allocation decisions make this idea particularly attractive. The ECB allocates around 10 % of its Public Sector Purchase Programme (PSPP) to bonds issued by "supranational institutions", including the European Investment Bank (EIB), which devotes a minimum of 25 % of total lending to environmental projects (Campiglio et al., 2016). Taken together, De Santis et al. (2018) provide some evidence suggesting that the purchases of the Eurosystem has reduced yields of green bonds and supported their issuance by non-financial corporations.

Within the framework of a stock-flow-consistent flow-of-funds behavioral model, Monasterolo and Raberto (2017) find that large-scale purchases of green sovereign bonds provide a key impetus for developing the green bond market with positive spillovers on green investment and employment. Green QE may accelerate the transition to a low-carbon economy. At the same time, the risk of stranded assets for the financial system is reduced. Another finding is that wealth inequality rises as capital gains following rising asset prices in the course of green QE exclusively benefit higher-wealth households as well as financial firms.

4.2 Credit easing

Also, the loan portfolio of banks could be assessed with respect to its environmental impact, and, in principle, the extension of loans to low-carbon activities may be incentivized. Central banks have already experimented with various schemes of targeted credit easing programs with the aim to revive lending to households and firms. In June 2012, the Bank of England launched the Funding for Lending Scheme that was intended to provide banks with a stable source of term funding at rates well below those prevailing in the market at that time. Access to the schemes was conditional on lending to households and firms, and later in particular to small and medium-sized companies

9 See website of the Climate Bonds Initiative: https://www.climatebonds.net.

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(Havrylchyk, 2016). At the back of contracting lending, the central bank of Hungary initiated the Funding for Growth Scheme (FGS) in 2013, under which interest-free refinancing loans were provided to credit institutions for lending to SMEs at a capped interest rate. Starting in 2014, the ECB issued two rounds of targeted longer-term refinancing operations (TLTRO I and II) and has announced a third round (TLTRO III) starting in September 2019. Within this scheme, the cost of refinancing is linked to the amount of loans banks extend to non-financial corporations and households. The more loans participating banks issue to non-financial corporations and households (except loans to households for house purchases), the more attractive the interest rate on their TLTRO borrowings becomes.

Hence, an alternative or complement policy to green QE would be to conduct targeted green refinancing operations. Central bank liquidity could be provided at preferential rates if the banks extend credit for low-carbon activities or for projects that sustain the ecological transformation of the economy. Similarly, a proposal has been made to differentiate rediscount rates, which means that banks extending credit to green investment can rediscount green loans at the central bank at lower rates (UN Environment, 2017).

4.3 Collateral framework for monetary refinancing operations

Collateral frameworks of central banks define the set of eligible collateral that financial institutions can use in operations with central banks as well as the haircuts imposed. These frameworks affect the rate of repurchase agreements (repo), liquidity and price in the secondary market. Central banks use several eligibility criteria for collateral. A high credit quality that is mostly derived from assessments by credit rating agencies is an eminent one. Note that a credit rating also determines the haircuts applied to the collateral. The fact that an asset is included in the list of eligible assets that can be pledged to borrow liquidity from central banks (like the fact that an asset is purchased directly by the central bank) could incentivize the issuance of larger quantities of those assets, increase their liquidity and improve the funding conditions of the issuer more generally. Against this backdrop, a thorough assessment of potential biases favoring high-carbon assets within the collateral framework would be useful. Accounting for climate risks in the collateral framework does not only entail a reassessment of eligibility; higher haircuts for high-carbon assets might also be considered to take into account high-carbon risks.

The proposals made in the literature constitute a major deviation from the principle of market neutrality prevailing in many central banks. According to that, monetary policy should safeguard macroeconomic stabilization and should not interfere with the microeconomic allocation of finance (Mersch, 2018). Indeed, a proper carbon tax (or administrative measures), to put a price on green house emmissions, should be best suited to internalize environmental externalities (OECD, 2013). Financial market participants would then necessarily take into account climate risks in their investments, which, as a consequence, makes monetary policy climate friendly without discretionary action by the central bank. However, the existence of "credit market failure" related to the creation of credit where market participants do not properly respond to price signals may point to the need of further tools, including monetary policy, to steer finance towards green projects (Campiglio, 2016). But whether "credit market failures" are empirically relevant is open to debate.

5 Concluding remarks

Climate change and climate policies have an impact on price and financial stability, therefore, the issue of climate change is of concern also to central banks (Monnin, 2018). Central banks can make a direct contribution to effective climate management and a sustainable economy, and they can also contribute indirectly by sharing their knowledge with a broader audience. They are well suited for monitoring the economic conditions for climate protection, as their mid- to long-term mandate goes beyond corporate reporting intervals, business cycles and legislative periods. Supervisors and central banks can facilitate the disclosure of financially relevant physical and transitional climate risks and stimulate the greening of finance via their economic research and their supervision of markets and their advice to regulators.

Apart from their core mandates, many central banks aim at carbon reduction or even carbon neutrality in their own operations. In addition to what they are already doing, they could, for instance, implement a transparent and environmentally friendly mobility concept for their employees, which may include business travel and commuting optimization (i. e. reduction) as well as shifts to alternative means of transport. Central banks should also integrate green finance and the relationship between climate change and the economy into their financial educational activities. Furthermore, they can fund climate and environmental research projects and use them to acquire the necessary know-how in the field. Central banks could also create an award for financial investments with a high potential for climate protection. They could contribute to the establishment of guidelines for financial service providers for the benchmarking of corporate environmental and social indicators.

The NGFS plans to produce several deliverables based on the experience of central banks and supervisors in assessing climate-related risks, collecting tools for (scenario) analysis, data processing, or macro models that endogenize climate risks. It also plans to compile best ESG practices on central banks own portfolios disclosure and management, to monitor green finance market dynamics and innovation and to screen the literature on greening monetary policy.

Central banks' incentives to disclose climate-related risks of corporates nourished hopes that falling renewable-energy costs would spark divestment out of "brown" assets which may eventually become stranded assets. Transparency and supervision, however, cannot prevent technological developments from improving the cost efficiency of fossil sectors too (Turner, 2019). Ultimately, it is the responsibility of policymakers to internalize the external costs of carbon emissions, via trading regimes, carbon taxes, renewable subsidies, restrictive regulations or a combination of those options. The full implementation of the Paris Agreement implys an operationalized commitment of all developed countries to cut their greenhouse gas emissions to (almost) zero by mid-century. A clearly defined path of emission cuts fostered by a gradually increasing shadow carbon price will reduce climate-related financial risks and create business opportunities for a change toward green prosperity.

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