Survey Note: The Implications of Climate Change for Central Banks in Emerging Market and Developing Economies

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1. Introduction

Climate change is a defining challenge of the 21st century. The global average temperature has increased by over 1°C since the pre-industrial period, and the land surface air temperature has risen twice as much as the global average temperature (IPCC 2019). The global average temperature is projected to rise by 0.5°C over the next decade and, if decarbonization does not occur, it could increase by 3-5°C or more by 2100 compared to pre-industrial levels, temperatures not seen in millions of years (IPCC 2018), well before homo sapiens. The conditions that have allowed modern societies to develop would thus disappear (Rockström 2020). Global warming appears to be accelerating, with the five hottest years on record having occurred in the past five years. Several planetary boundaries related to Earth systems – boundaries within which the planet is assessed by scientists to be in a safe zone – have been crossed (Rockstöm et al. 2009), and the evidence suggests that the planet is approaching several tipping points (Lenton et. al. 2019). Human activity accounts for almost all of global warming, in particular via greenhouse gas (GHG) emissions, with crucial implications for the role of economic and financial policies in keeping global warming below 2°C – the level considered safe by scientists (IPCC 2018).

Climate change is likely to hit developing economies earliest and hardest, a pattern that is already apparent. 2019 saw a surge in rainforest wildfires, notably in Brazil, the Democratic Republic of Congo and Indonesia, the wettest monsoon in India in 25 years, the second strongest hurricane on record in the Bahamas, and the third deadliest tropical cyclone on record in Mozambique. So far in 2020, wildfires in the Brazilian Amazon have increased by 30 percent relative to 2019, huge locust swarms, which are connected to climate change, have threatened the livelihoods and food supply of tens of millions of people across three regions (East Africa, the Middle East, and South Asia), and floods have cumulatively displaced tens of millions of people and destroyed crops in East Africa, China, and South Asia. Echoing these intensifying disasters in numerous countries, a group of more than 11,000 scientists has warned about the potentially catastrophic and irreversible effects of climate change, including on human populations – about 85 percent of which live in developing countries (Ripple et al. 2019).

Governments have a key role to play in climate policy. Many of the critical policies to address climate change and accelerate decarbonization, from carbon pricing to public investment in clean energy infrastructure and environmental regulation, fall within the remit of governments (IMF 2019a). By implication, key actors include various financial regulators. In the context of the COVID-19 pandemic crisis, it has been argued that finance ministries have a crucial role to play in designing climate-compatible stimulus packages, notably by developing recovery packages from the perspective of long-term strategy and sectoral transformation (Coalition of Finance Ministers 2020).

Furthermore, it is increasingly acknowledged that climate change is a source of structural change in the economy and financial system, and thus falls within the mandate of central banks (NGFS 2019). In line with global climate dynamics and the scale of the required economic transformation, climate

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change is viewed by a large number of central banks as "one of the most significant structural forces shaping the global economy" (NGFS 2020a).[2] Five interrelated factors underpin this view. First, the rising frequency and severity of weather and climate extremes, such as those described above. Second, the long-term effects of gradual warming, including seal level rise, ocean acidification, and changing precipitation patterns. Third, the threat posed by irreversible Earth system tipping points, such as the irrevocable melting of parts of the Antarctica or the rapid die-off of the Amazon rainforest. Fourth, the economic and financial implications of policy action to address climate change. And fifth, potentially significant technological disruptions and behavioral changes associated with deep decarbonization. The macroeconomic and financial implications of climate change are set to become ever more important as global warming accelerates. Understanding the implications of climate change for central banks is thus critical, notably in EMDEs, which are expected to be most affected by climate change.

The relevance of climate change for EMDE central banks is reinforced by three considerations. First, the high degree of uncertainty around scientific and economic projections related to climate change (IPCC 2018, IMF 2020). Second, the significant tail risks associated with the possible existence of tipping points that could be reached at an uncertain date in the near future (Lenton et al. 2019). Third, countries' commitments under the framework of the Paris Agreement. In particular, Article 2 of the Paris Agreement calls for "making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development" – underscoring the critical role of finance in climate policy (UNFCCC 2016).

This note provides an overview of the implications of climate change for central banks, with a focus on developing economies. Section 2 briefly reviews the literature on the implications of climate change for central banks. Section 3 summarizes climate-related policy developments in EMDE central banks. Section 4 discusses broad open questions regarding the implications of climate change for central banks that have been raised in recent research and policy work.

2. Implications of Climate Change for Central Banks in EMDEs

Awareness of, and research on, climate-related risks is growing. Following Mark Carney's seminal speech on the "tragedy of the horizon" (Carney 2015), in 2017 the Network of Central Banks and Supervisors for Greening the Financial System (NGFS) was created. The NGFS is a group of central banks and supervisors that aims to further the development of environment and climate risk management and to mobilize finance to support the transition to a sustainable economy. Reflecting the growing consensus in the central banking community on the significance of climate change for financial stability and central banking, the NGFS comprises 69 members, a third of them being EMDEs.

Climate-related risks are rapidly becoming a core area of focus for central banks. In 2018, the NGFS noted that climate-related risks pose financial risks and that central banks and supervisors have a role to play to ensure the resilience of the financial system to these risks (NGFS 2018). In 2020, the NGFS recommended that central banks consider the possible effects of climate change on the economy, emphasizing that such effects may be relevant to monetary policy even if they only materialize beyond the conventional three- to five-year policy horizon (NGFS 2020a). Furthermore, the NGFS emphasizes the need to understand the possible implications of climate change for the design of monetary regimes.

The global nature of the climate change challenge means that the role of EMDEs fits within the context of a global effort. Many aspects of climate change, such as the potential tradeoffs between physical and transition risks discussed in this section, are global in nature. This complicates the calibration of individual countries' reaction. Given the global nature of climate risks, some observers have emphasized the need for coordinated collective action (Pereira da Silva 2020). The nature of the role of individual developing countries in the global transformation to address climate change will necessarily be

[2] It should be noted that, as of September 2020, the central banks of the United States and Brazil, the world's second and sixth highest GHG-emitting countries, respectively, were not members of the NGFS.

country-specific and will depend on local conditions. In particular, the relative weight given to adaptation and mitigation will and should vary across countries. Small Island Developing States (SIDS) face a disproportionate risk of flooding (IPCC 2018), which in turn poses an existential threat to these countries.[3] On the other hand, the largest EMDEs account for a significant share of current global GHG emissions, implying that mitigation action in these countries is decisive for global decarbonization.

This section provides an overview of the implications of climate change for central banks' financial stability mandate and monetary policy, focusing on risk drivers, transmission channels, and policy implications. The third sub-section summarizes policy discussions on whether and to what extent central banks, including in EMDEs, should play an active role in climate change adaptation and mitigation.

a. Financial Stability

It is increasingly acknowledged that climate change may create systemic risk. The characteristics of climate-related financial risks are unique: far-reaching impact, unforeseeable nature, irreversibility, and dependency on short-term actions (NGFS 2019). Climate risk is systemic in nature because it has the potential to affect the entire economy and financial system (Aglietta and Espagne 2016, Krogstrup and Oman 2019).

The relevant time horizons for climate and financial impacts can differ. While risks in the financial sector tend to build up over prolonged periods, they typically materialize at high frequency. Climate change impacts that are relevant to human societies can occur slowly, with disequilibria accumulating unnoticed over extended time periods, or suddenly and unpredictably, possibly occurring at specific locations and generating contagion effects in other regions (Aglietta and Espagne 2016). This raises the question of the relationship between the time horizons relevant to climate policy and financial stability. In an influential speech, Mark Carney noted that this tension creates a "tragedy of the horizon": when climate change becomes a defining issue for financial stability, it may be too late (Carney 2015).

Two main channels have been identified: physical risks and transition risks (Carney 2015). Physical risks correspond to financial losses resulting from more frequent and severe weather and climate extremes (e.g., droughts, storms, wildfires) and from the chronic effects of changing climate patterns (e.g., sea level rise). Transition risks are financial losses associated with a rapid or disorderly low-carbon transition. In turn, a disruptive or disorderly low-carbon transition may be triggered or accelerated by policy changes, technological disruptions, or behavioral changes. Below I discuss each risk in turn and provide a brief summary of discussions on policy options to address these risks.

i. Physical Risks

Physical risks are significant in EMDEs. Physical risks can be grouped into two broad categories: those related to extreme weather events and those related to gradual warming. Physical risks tied to extreme weather events include the destruction of infrastructure and other kinds of physical capital, and the diversion of resources for adaptation. Damages linked to gradual warming are already having a large impact on developing countries, where a growing amount of uninsured losses have been crystalized in recent decades (IAIS 2018). Two physical risks related to gradual warming are lower agricultural yields and lower labor productivity (Batten 2018). These risks are highly relevant to developing economies, which typically have a higher share of agriculture in GDP and exports than advanced economies, and many of which have very large populations living in coastal areas. Independently of its impact on GDP, gradual warming creates food security and water security risks in EMDEs (IPCC 2018). Other risks stemming from gradual warming include rising sea levels and higher temperatures. Sea level rises of 2 meters could displace close to 200 million people by 2100 (Bamber et al. 2019). Even if global warming

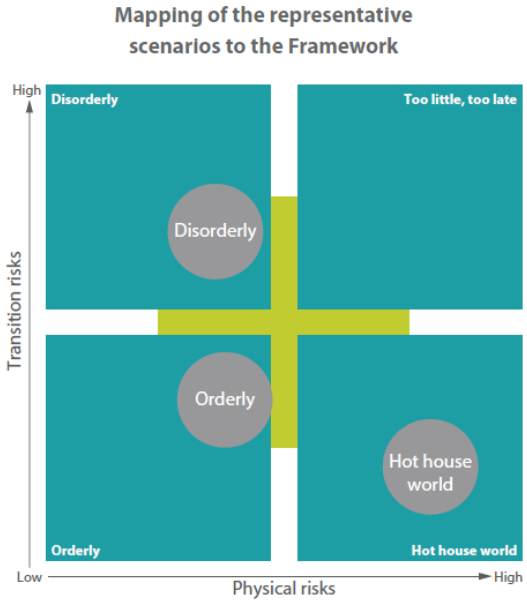
[3] Several countries, including China, Papua New Guinea and Vietnam, have already relocated communities due to their vulnerability to flooding.

were limited to between 1.5°C and 2°C, it could result in sea level rises of 6 meters over the long term (Fischer et al. 2018). Due to rising temperatures that would result from a "business-as-usual" scenario, over the next 50 years 1 to 3 billion people – all of them living in developing countries – could be displaced or forced to live in uninhabitable conditions (Xu et al. 2020). In turn, such enormous dislocations could cause mass migrations and severe and persistent conflict (Abel et al. 2019, Stern 2016). Sea level rises may eventually lead to the unprecedented disappearance of some sovereign states – Small Island Developing States (SIDS) – for reasons unrelated to wars, with potentially significant geopolitical and financial consequences. The enormous adaptation needs of such countries, and possibly the need, ultimately, to relocate their populations, will pose a collective action problem, since such measures are unlikely to be financed by the private sector. Finally, gradual warming is projected to lead to the spread of some vector-borne diseases, such as malaria, including through potential shifts in their geographic range (IPCC 2018).

An example of the materialization of physical risks is the floods that affected Thailand in 2011. These floods, the costliest in the Thailand's history, imposed direct losses of over 10 percent of GDP and led to a 2.5 percent contraction in the economy. Among other impacts, the floods led to a decline in the Thai stock market index of over 8 percent in the immediate wake of the disaster, and of about 30 percent after 40 trading days (IMF 2020a).

The economic cost of climate change in EMDEs could be considerable. Without adequate mitigation policies, all regions would experience a major decline in GDP per capita by 2100 (Khan et al. 2019). Furthermore, developing economies are likely to suffer more from climate change than advanced economies (Diffenbaugh and Burke 2019). Some models suggest that GDP losses could amount to a quarter of global GDP, with even stronger impacts in Asia (Burke et al. 2015). In all of these studies, a key caveat is that impacts could be much greater, given the radical uncertainty associated with "a physical, social and economic phenomenon that is constantly changing and involves complex dynamics and chain reactions" (Bolton et al. 2020). A key point, with significant relevance to central banks, is that damages from climate change increase non-linearly with global warming and thus over time, with the risk of tipping points intensifying dangerously above 2°C (Lenton et al. 2019). This point is captured by the representative climate scenarios developed by the NGFS (Figure 1). While the time dimension is not explicitly considered, these scenarios nevertheless imply an inverse function relating physical and transition risks, with costs rising over time between the bottom-left scenario ("Orderly") and the top-right scenario ("Too little, too late"). This implies that, without mitigation, public authorities and the private sector will over time build up considerable contingent liabilities.

Figure 1. NGFS Representative Climate Scenarios

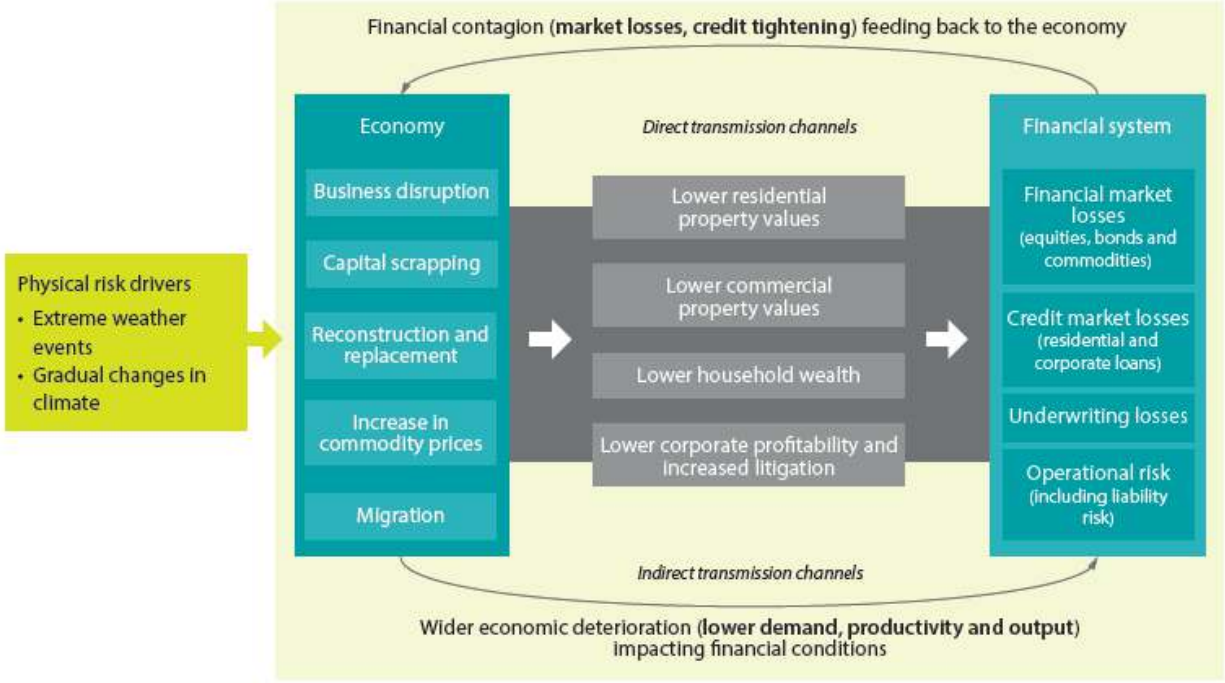


Source: NGFS (2020b)

In turn, several channels link damage from climate change to financial risks. These channels include (but are not limited to) lower property values, lower household wealth, and lower corporate profitability and household income (NGFS 2019). These linkages include both direct and indirect channels and imply potentially strong feedback loops between the economy and the financial system (Figure 2). Thus a corollary of EMDEs' significant physical risks is that the climate-related financial stability risks are

commensurately large. The empirical evidence suggests that climate risks are mispriced in financial markets (IMF 2020, Hong et al. 2019, Addoum et al. 2019, Sowerbutts 2016, BlackRock Institute 2015).[4]

Figure 2. Linkages Between Physical Risks and Financial Risks



Source: NGFS (2019)

Sovereign bonds are a further channel that links physical and transition risk drivers to financial risks. It has been argued that unsustainable economic activities in developing countries expose countries to climate risks and asset stranding in their transition to a sustainable economy.[5] Pinzón et al. (2020) note that pressures to align sovereign bonds with environmental sustainability will increase in the next decade, putting sovereign bonds under pressure, as they link macroeconomic performance and capital markets. These authors argue that the crystallization of such risks can raise borrowing costs (i.e., trigger a widening of sovereign spreads) and lead to impairments in credit quality and reduced access to finance for sovereigns. They find that Argentina and Brazil are the G20 countries that are most vulnerable to this risk, with 28 percent of and 34 percent of their sovereign bonds exposed to an anticipated tightening of climate and anti-deforestation policy (both transition risks – see the discussion in the next sub-section) by 2030. This channel is significant, given the size of the local currency emerging market sovereign bond market ($8 trillion as of April 2019), which accounts for about 40 percent of the emerging market bond market (McPartland 2019).[6] Conceivably, a further channel could operate through the effects of the materialization of corporate and financial risks on the borrowing costs of the sovereign, for example through the interaction of financial crises and the bank-sovereign nexus.

[4] According to costly trade theory, long-term assets are susceptible to mispricing as a result of capital needs and the risk of arbitrage (Shleifer and Vishny 1990, 1997) (Krogstrup and Oman 2019).

[5] For instance, by threatening essential ecosystem services (clean water, flood regulation).

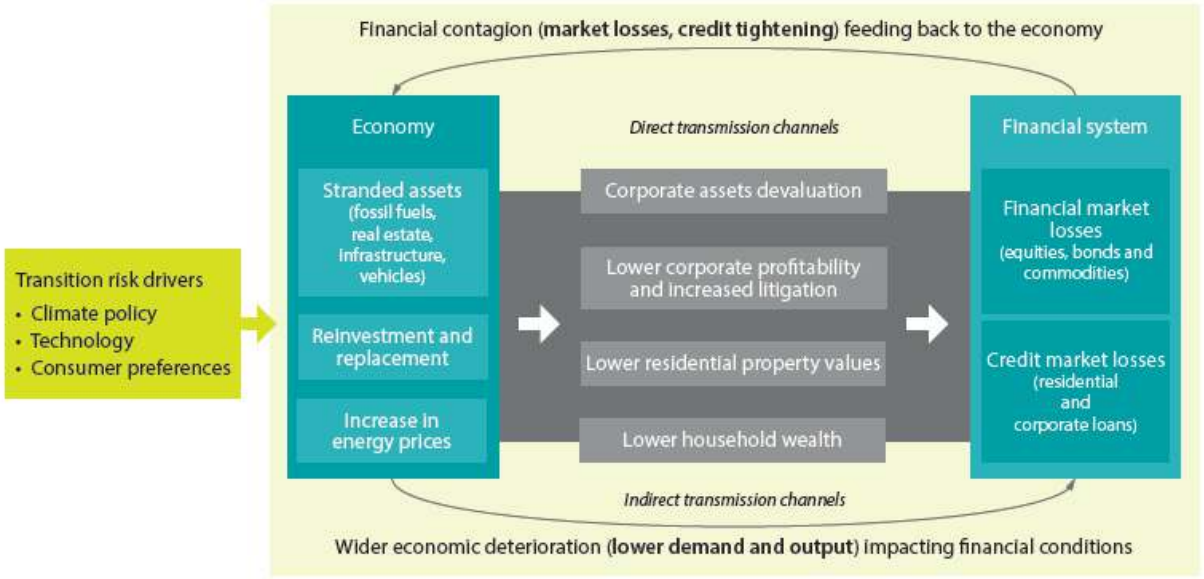
[6] A distinct but related empirical finding is that that countries that are vulnerable to climate change face a higher cost of debt, on average (Kling et al. 2018).

ii. Transition Risks

Transition risks are another source of potentially large impacts on developing economies and their financial systems. As noted above, financial losses from a rapid or disorderly low-carbon transition may be triggered or accelerated by policy changes, technological disruptions, or behavioral changes. A particularly significant transition risk is stranded assets – a collapse in the value of fossil fuel assets due to a perception that the vast majority of fossil fuel reserves are unburnable, given insufficient remaining carbon budgets (Carney 2015). Stranded assets are a significant risk for fossil fuel exporting EMDEs. Indeed, international climate objectives enshrined in the Paris Agreement (keeping global warming well below 2°C) require leaving around two-thirds, on average, of oil, gas and coal reserves in the ground (McGlade and Elkins 2015). The existence of transition risks, especially stranded assets, underscores the importance for policies of following a preannounced, predictable path – which could be modified over time – in order to maximize the credibility of the central bank and the policy strategy.

Transmission channels for transition risk drivers are similar to those for physical risks. Channels include, but are not limited to, corporate asset devaluation, lower corporate profitability, lower property values, lower household wealth and incomes, and stranded jobs (which are an indirect source of major fiscal risks). As in the case of physical risks, potentially strong feedback loops link the financial system to the economy, notably via financial contagion risks (Figure 3).

Figure 3. Linkages Between Transition Risks and Financial Risks



Source: NGFS (2019)

While deep decarbonization could raise growth, the materialization of transition and/or physical risks will exert downward pressure on growth. Radical innovation and waves of technological change could boost productivity and increase resilience (Meckling and Allen 2020). This consideration is relevant for EMDEs, given the need to invest around $90 trillion in infrastructure to 2030, which is much more than the existing stock (New Climate Economy 2018). About 70 percent of these investments need to take place in EMDEs. Reflecting the scale of the needed infrastructure, cumulative climate investment opportunities are estimated by the International Finance Corporation at $29.4 trillion across six urban sectors in emerging market cities to 2030 (IFC 2018). On the other hand, the materialization of transition and/or physical risks will put downward pressure on growth. And while the low-carbon transition could create an estimated 15 million net new jobs in Latin America and the Caribbean (Saget et al. 2020), this would occur in a context of considerable job losses due to the COVID-19 pandemic crisis (IMF 2020b).

Physical and transition risks are inversely related. Aggressively mitigating climate change reduces physical risks but increases transition risks, while a "business-as-usual" scenario would entail rising physical risks but would reduce transition risks (at least until aggressive and possibly disorderly policy action is taken in the future, when the physical impact of severe climate change prompts policy changes). Importantly, however, even rapid decarbonization is unlikely to completely eliminate physical risks.

Policy implications are wide ranging. Emphasizing both the uncertainty around the potential economic and financial impact of climate change and the urgency of mitigation and adaptation, the NGFS has made six recommendations (NGFS 2019): (1) integrating climate-related risks into financial stability monitoring and micro-supervision; (2) integrating sustainability factors into own-portfolio management; (3) bridging the data gaps – specifically, sharing data relevant to Climate Risk Assessment and, where possible, making them publicly available in a data repository; (4) building awareness and intellectual capacity and encouraging technical assistance and knowledge sharing; (5) achieving robust and internationally consistent climate and environment-related disclosure; and (6) supporting the development of a taxonomy of economic activities. An additional implication is the need to fill the modeling gap that stems from the lack of appropriate models combining physical/climate and economic/financial linkages.

iii. Policies to Address Climate-Related Financial Risks

Policy implications that are being considered in policy discussions fall into five main categories:

- **Supporting the creation of agencies responsible for collecting, validating and disseminating climate-relevant data.** The data needed to manage climate financial risks are complex and fragmented, suggesting that central banks – in countries where they also act as financial regulators – may need to support such efforts (Battiston 2019).

- **Developing a taxonomy of economic activities and/or financial assets.** The NGFS emphasizes the role of a taxonomy in the transition to low-carbon economy and the identification of activities and assets that are exposed to climate and environment-related risks (NGFS 2019). The NGFS identifies three main objectives: for financial institutions to identify and manage climate and environmental risks, to deepen the understanding of risk differentials across asset types, and to mobilize capital for low-carbon investments. Challenges related to the development of a taxonomy are threefold. First, assessing whether and to what extent assets are environmentally harmful or helpful is a prerequisite to incorporating climate change considerations into central bank operations (described in sub-section C below) – notably because central banks influence assets through their operations. Second, central banks have to assess whether underlying financial markets can provide efficient pricing and volume of instruments in order for the central bank to achieve its immediate objective. Finally, given the considerable climate-relevant data gaps mentioned above, there are capacity challenges within central banks that complicate the development of a taxonomy of sustainable and unsustainable economic activities and financial assets.

- **Accounting for climate-related risks in prudential frameworks.** This is found to be compatible with existing mandates, conditional on a thorough assessment of the financially systemic nature of climate risks (Monnin 2018, Schoenmaker and Tilburg 2016). Relevant tools include reserve, liquidity and capital requirements, loan-to-value ratios, and caps on credit growth, as well as sectoral capital buffers targeting credit to particularly climate-exposed sectors (for example following macroprudential policy design as in Galati and Moessner 2017, Cerutti et al. 2017) (Krogstrup and Oman 2019). The IMF suggests that policymakers may consider mandating coverage for climatic disaster risks for some assets (e.g., those used as loan collateral), subsidizing climatic disaster insurance, or enabling insurer-of-last-resort solutions where economic agents have difficulty obtaining insurance (IMF 2020a).[7] Prudential frameworks should continue to be guided by financial stability objectives.

[7] One proposal, in which central banks could conceivably play a role, is for public authorities to develop a range of regulated ecological investments that are accessible to a large number of investors and are transparent (Rey 2019).

Furthermore, institutional safeguards, such as independent agencies, could be created to prevent potential abuse or leakage associated with climate-compatible prudential frameworks.

- **Incorporating climate risks into stress tests** (NGFS 2019). Stress-testing research and macroeconomic modeling that would be required to measure climate-related financial risks could also help assess whether climate-related financial risks should be used more generally in the calibration of macroprudential policies as discussed above (Campiglio et al. 2018).

- **Incorporating climate risks into the management of central bank reserves.** Fender et al. (2019) examine the issue of including sustainable assets in central banks' reserve portfolios and conclude that this can be done without forgoing safety and return. A caveat is that the accessibility and liquidity of such assets is currently constrained. In response to increasing demand for climate-friendly investments, in 2019 the BIS created an open-ended fund for central bank investments in green bonds, which is aimed at helping central banks incorporate sustainability objectives in their reserve management.[8]

b. Monetary Policy

Channels linking climate change to macroeconomic effects are relevant for monetary policy. The climate risks surveyed above, which encompass the effects of both climate change and its mitigation, are related to several channels that link climate change to macroeconomic impacts. Most of these channels are relevant for monetary policy, and some are potentially contradictory (NGFS 2020a). These channels are wide ranging. They comprise output, consumption, investment, productivity, employment, wages, international trade, exchange rates, inflation, and inflation expectations. For example, more frequent and severe extreme weather events could lower output via the destruction of crops, infrastructure, supply chains, and tourism. Gradual warming could reduce output via lower labor productivity and investment being diverted to climate change mitigation. Domestic and imported inflation could become more volatile due to the impact of both extreme weather events and gradual warming on agricultural crops, housing, and energy prices. The latter risk is proportional to the share of energy and food in total imports (and ultimately in the consumer price index), which is typically significant in EMDEs.

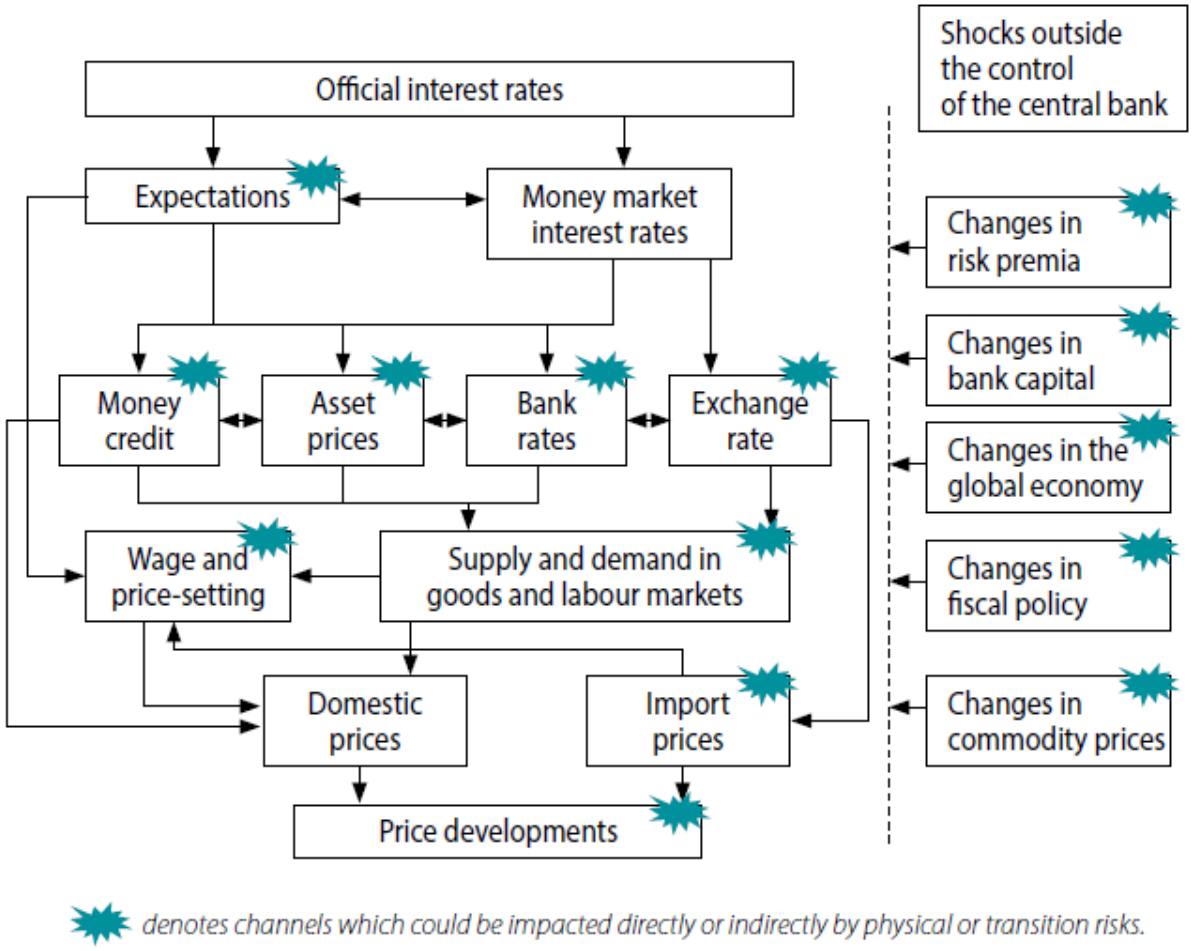
Climate change is thought to have significant implications for the conduct of monetary policy. The NGFS has identified five ways in which climate change affects the conduct of monetary policy, all of which are relevant for EMDEs (NGFS 2020a). First, climate change and its mitigation affect macroeconomic variables that are key for the conduct of monetary policy across many different time horizons – climate change is part of monetary policy contexts and will become increasingly prevalent. This point relates to the channels connecting climate change to monetary policy-relevant macroeconomic variables, described above. Second, climate change could complicate central banks' assessment of its room for maneuver. Climate change and related policy responses may affect productivity and long-run growth, which can in turn affect the estimation of the neutral interest rate, a key variable in monetary policy (Brainard 2019). Third, climate change could affect monetary policy transmission channels (Figure 4). For instance, climate change may have effects on banks' balance sheets and change economic agents' expectations – potentially impairing the transmission of monetary policy via larger stranded assets and increased credit risk. Fourth, there is a consensus that central banks should incorporate climate risks to their macroeconomic models and forecasting tools. Finally, central banks need to investigate whether climate change may have fundamental implications for the design of monetary regimes.

Central banks may need to reflect climate risks in their collateral frameworks and asset portfolios. Some observers argue that central banks' mandates require them to accurately reflect climate financial risks in their asset portfolios (Monnin 2018). It is argued that doing so would be consistent with sound monetary policy implementation and conservative risk assessment, that it would mitigate central banks' exposure to climate risks, and that it would help reduce the relative market value of carbon-intensive

[8] https://www.bis.org/press/p190926.htm

assets, increasing incentives for investors to shift capital to low-carbon sectors (Krogstrup and Oman 2019). Finally, such a shift would help signal to the financial sector the importance incorporating climate risks into their asset valuation practices (NGFS 2019).

Figure 4. Linkages Between Climate Risks and Monetary Policy Transmission Channels



Source: NGFS (2020a)

The impact of weather and climate extremes on inflation is a key channel connecting climate risks to monetary policy. Climate oscillations such as the El Niño-Southern Oscillation and the Indian Ocean Dipole are linked to weather extremes (intense storms and droughts). As a result of gradual warming, developing countries that border the Pacific and Indian Oceans are projected to be increasingly affected by climate oscillations and their impact on agriculture. Increased rainfall can cause crop shortfalls, putting upward pressure on food prices. In general, weather-related disturbances can pose a standard dilemma for central banks facing supply shocks: stabilizing inflation or economic activity (Cœuré 2018). In EMDEs, the problem posed to central banks is likely to be different. In the typical case of a small open developing economy in a flexible exchange rate regime, the external channel of monetary policy plays a major role. In small open economies, the exchange rate is a key determinant of inflation and growth, and this can lead to inflationary shocks via exchange rate depreciation when the central bank lacks credibility. In the wake of the COVID-19 crisis, hard hit EMDEs could face fiscal sustainability risks. In this context, monetary policy tightening in response to a weather-related inflation shock could be counterproductive, as it could have contractionary economic effects while not addressing the climatic cause of the inflation shock and possibly undermining the central bank's credibility. This could in turn lead to a depreciation of the exchange rate, further pushing up inflation. To avoid monetary policy responses to climate shocks

that have adverse economic effects, central banks may need to develop new modeling approaches to distinguish climate shocks from other drivers of inflation.

Climate change could force central banks to rethink their policy frameworks. Beyond the channels discussed above, climate change could force central banks to rethink their policy frameworks. In particular, catastrophic climate change could exhaust central banks' conventional policy space through two mechanisms: (i) by making the distribution of shocks more fat tailed; and (ii) by increasing the risks of monetary policy mistakes due to an increase in the signal-to-noise ratio in the disentanglement of the variation in the data relevant to assess the medium-term inflation outlook (Cœuré 2018).

Some observers and evidence suggest that unconventional monetary policies may be a source of climate risk. It has been argued that the monetary authorities of several large countries have for the past decades facilitated oil production by supporting the oil industry's capital expenditure (CAPEX) through low interest rates and unconventional monetary policies (Lepetit 2020). CAPEX projections for oil extraction play a key role in NGFS climate scenarios, as reflected by their sharply divergent paths in the "Orderly" and "Hot house world" scenarios (see Figure 1). Furthermore, there is evidence of carbon intensity in the portfolios purchased in the large-scale asset purchase programs of the central banks of some advanced economies (Matikainen et al. 2017, Battiston and Monasterolo 2019).[9] This raises the question of whether conventional and unconventional monetary policies may have facilitated the build-up of climate risks, and of possible policy implications.

Beyond known or presumed transmission channels, radical uncertainty around climate change suggests that new channels could emerge or be discovered. A fundamental aspect of climate change is the deep uncertainty that exists with respect to the biogeochemical processes that it may trigger (Bolton et al. 2020). Crucially, tipping points have been shown to exist but to be very difficult to estimate and to have the potential to generate a global cascade of tipping points (Lenton et al. 2019). Put differently, there are both "unknown unknowns" and possibly (*ex-ante*) "unknowable unknowns" around the relationship between climate and economic systems. This a key reason why the probability and impact of nonlinear natural and economic phenomena are largely impossible to appropriately integrate into existing models (Bolton et al. 2020). Climate change could uncover previously hidden interdependencies between the economy and natural systems, revealing new and potentially enormous disruptions and costs (Krogstrup and Oman 2019). For instance, climate change could generate entirely new climates (IPCC 2014).

c. Climate Change Adaptation and Mitigation

Adaptation is likely to be a climate policy priority in many EMDEs. As noted in the introduction, developing countries are expected to suffer most from the impacts of climate change. EMDEs are thus likely to prioritize adaptation in their climate policy strategies. Infrastructure disruptions are pervasive in developing countries, with adverse effects on economic development, notably through impacts on firms and jobs. Rapid population growth and more frequent and more severe natural disasters due to climate change underscore the urgency for EMDEs of climate change adaptation (Hallegatte et al. 2019).[10] In this context, the incorporation of climate change into EMDE central banks' financial stability and monetary policy frameworks could play an important role by making climate risks more transparent and highlighting the financial risks and economic costs associated with delayed climate change adaptation. Adaptation policies entail extensive dialogue among different policy areas and involve tradeoffs. Central banks could potentially contribute significantly to these processes by bringing their expertise and credibility to bear on the policy work involved in adapting to climate change.

[9] There is also evidence that the asset portfolio of the Bank of England's Corporate Bond Purchase Scheme is consistent with an average temperature increase of 3.5°C above pre-industrial levels by 2100 (Bank of England 2020). An analysis finds that purchases of the Federal Reserve's COVID-19 related Secondary Market Corporate Credit Facility were, as of July 10, 2020, significantly overweight in the energy sector, which is composed of oil, gas and coal value chain companies (InfluenceMap 2020).

[10] Lenton et al. (2019) define the emergency to act as the product of risk and urgency, with the latter being defined in emergency situations as the reaction time to an alert divided by the intervention time left to avoid a bad outcome.

Active climate mitigation may fall under the mandates of some EMDE central banks, but defining mitigation within central bank mandates poses a challenge. Some observers argue that the extent to which a central bank could or should play an active role in climate mitigation depends on its mandate and the extent to which it is best placed to correct certain market failures (Volz 2017). A review of central bank mandates finds that, of 133 central banks in the sample, 12 percent have explicit sustainability mandates and 29 percent have a mandate to support the government's policy priorities, which typically include sustainability or development goals.[11] This suggests that these central banks, most of which are in EMDEs, could play an active role in mitigation (Dikau and Volz 2020).[12] Central banks in EMDEs are viewed by some as having a strong institutional standing that allows them to shape policy outcomes (Dikau and Volz 2020). Yet the question of whether and to what extent central banks should play a role in mitigation is contentious and far from settled. Notable issues relate to potentially conflicting central bank objectives, as well as risks concerning central banks' accountability (Volz 2017, Krogstrup and Oman 2019).[13] At the same time, most central banks have price and/or financial stability mandates, both of which are likely to be affected by climate change. Framing climate change as a separate part of the mandate raises questions related to the governance of the central bank and the determination of its mandate. Incorporating climate change within existing mandates could offer an alternative path that would enable the use of some existing policy instruments. How best to do so is an area of active research.

Independently of their mandates, central banks are being called on to play a role in mitigation. In addition to incorporating climate risks into prudential frameworks and monetary policy implementation, Stern (2016) identifies five areas for central banks to help steer the economy to a low-carbon transition: encouraging stable and credible policy frameworks for sustainable infrastructure; addressing capital market imperfections (e.g., the availability and costs of long-term debt finance); communicating strongly on climate risks not priced by financial markets; helping scale up the role of multilateral development banks and national development banks; and promoting green financing instruments and markets.

A range of tools is at the disposal of central banks that envisage an active role in mitigation. Depending on whether a central bank also acts as the financial regulator, relevant policy tools include green microprudential regulation, disclosure requirements, Environmental and Social (E&S) risk management standards, reserve requirements, macroprudential regulation, climate stress tests, climate-risk capital surcharges, green financial market development, and potentially more controversial policies such as credit allocation policies and central bank assistance to development banks (Dikau and Volz 2019).[14] Another possible tool is asset purchase programs focused on low-carbon assets or that exclude polluting assets (Krogstrup and Oman 2019).

Central banks' response to the COVID-19 crisis is seen by some as critical for mitigation. A report by the Coalition of Finance Ministers for Climate Action (Coalition of Finance Ministers for Climate Action 2020) notes that central banks have the tools needed to ensure that their responses to the COVID-19

[11] For example, the mandate of the central bank of Bangladesh includes as a secondary objective supporting economic growth and development. The central bank has interpreted greening the financial system and the economy as within its mandate (Bangladesh Bank 2011).

[12] Most often, this objective is subject to not impinging on the central bank's ability to pursue its primary objective (typically price stability).

[13] The economic case for second-best policies for climate change mitigation, including monetary and financial policies, is based on the theory of the second best (Lipsey and Lancaster 1956). Second-best policies are justified when there are multiple market failures that cannot be corrected independently, such that correcting only one externality with one instrument may not be enough (Lipsey and Lancaster 1956). Markets typically suffer from multiple externalities (Dixit 2009, Kapp 1950), and this is also the case for the setting in which the GHG externality occurs (Stern 2006, High-Level Commission on Carbon prices 2017) (Krogstrup and Oman 2019).

[14] For instance, higher capital requirements could be applied for carbon-intensive credit growth (Schoenmaker and Tilburg 2016). Basel capital adequacy requirements aim to reduce systemic risks of depository institutions, with potential implications for economic outcomes (Krogstrup and Oman 2019). Capital and liquidity requirements under the Basel III prudential framework do not explicitly include climate-related risk assessments for bank exposures (BCBS 2016). As a result, increasing climate risk-taking may come at a lower capital cost than what is desirable from a systemic financial stability perspective.

crisis "do no harm" with respect to climate change. For instance, central banks can decide not to provide liquidity to companies whose activities are inconsistent with climate goals. Similarly, Dikau et al. (2020) argue that, to avoid locking the economy into a high-carbon recovery and to fulfil their financial stability mandate, central banks must align their crisis response measures with Paris Agreement climate goals.[15] To do so, the authors identify five priorities: collateral frameworks, asset purchases, refinancing operations and crisis facilities, prudential measures, and management of central bank portfolios.

3. Climate-Related Policy Developments in EMDE Central Banks

EMDE central banks have been at the forefront of the incorporation of climate risks into financial regulation and monetary policy. Dikau and Volz (2019) conduct a comprehensive review of these developments, which is summarized below. These initiatives have revolved around four broad categories, with elements of both climate risk-focused and climate finance-promoting policies (Krogstrup and Oman 2019):

- **Disaster risk management.** Bangladesh Bank (BB) has played a proactive role in addressing the country's regular cycles of flooding. BB has since 2008 led planning and action on climate change, including by prompting banks to incorporate environmental risk in lending decisions and promoting green banking by establishing a Green Transformation Fund in 2016 (IMF 2019b).[16]

- **Green microprudential and macroprudential regulation.** The People's Republic of China (PRC), Brazil, Lebanon and Bangladesh have all implemented climate-friendly financial regulations. The PRC's engagement with green financial regulation began in the 1980s (Zadek and Chenghui 2014). In 2006, the People's Bank of China (PBoC) created a national database to centralize disclosed information on credit, administrative penalties, and environmental compliance of non-financial corporations. In 2007, the PBoC, the Ministry of Environmental Protection and the China Banking Regulatory Commission jointly launched the Green Credit Policy, which focuses on the banking system, the insurance sector, and securities markets. Brazil has been at the forefront of climate-friendly macroprudential regulation. In 2011, the Banco Central do Brasil extended its capital adequacy requirements under Pillar 2 of Basel II to require banks to account for their exposure to environmental risks (Banco Central do Brasil 2011). Furthermore, banks are required to conduct environmental risk stress testing (Banco Central do Brasil 2017). Banque du Liban has implemented differential reserve requirements to incentivize banks to increase the share of green lending projects in their loan portfolios (Banque du Liban 2010). In 2009, Bangladesh Bank (BB) introduced a revolving refinancing scheme for banks, with financing for green projects (IMF 2016). In 2011, BB introduced policy guidelines for green banking and guidelines on environmental risk management. In 2015, BB introduced mandatory green finance credit targets, followed by the issuance in 2016 and 2017 of integrated and environmental risk management guidelines for financial institutions. In 2019, the central bank of Morocco announced that it would conduct a study on climate risks in Morocco. In 2020, the Central Bank of the Philippines approved a Sustainable Finance Framework to safeguard the financial system from physical and transition risks, with the Governor of the central bank announcing that banks were to adopt a transition plan "with specific timelines to implement the board-approved strategies and policies integrating sustainability principles into their corporate governance and risk management frameworks as well as in their strategic objectives and operations" (IEEFA 2020).

- **Taxonomies and green financial market development.** In 2015, the PBoC published the world's first official green bond taxonomy, which aims to unify standards for green bond issuance (PBoC

[15] The identified rationale is fourfold: (1) ensuring that climate risks are accurately reflected in central banks' balance sheets and operations; (2) minimizing climate-related risks for regulated financial institutions; (3) minimizing systemic climate-related risk; and (4) supporting governments' efforts to scale up sustainable finance in line with Paris Agreement objectives and Sustain able Development Goals.

[16] A related initiative outside the central banking sphere is the creation of the African Development Bank's Adaptation Fund, which aims to increase African countries' resilience to the negative impacts of climate change.

2016). Since 2015, the Reserve Bank of India (RBI) has issued green bonds to support green energy development. National, regional and multilateral development banks have played an active role in developing green bond standards, such as the Asian Development Bank's Green Bond Framework (ADB 2020).

- **Climate-friendly credit allocation policies.** In Brazil and China, the central bank has focused primarily on suppressing credit to polluting sectors, whereas national development banks have been more active in supporting credit to green sectors. In Bangladesh, BB has used credit guidance policies to support, and encourage private-sector lending to, green sectors. Key BB green credit allocation programs include targeted refinancing lines from 2009, followed by additional green refinancing lines in 2015. In 2016, BB created a Green Transformation Fund, and thereby a further green refinancing window of around $200 million targeting loans for imports of environmentally friendly machinery aimed at increasing the sustainability of the leather and textiles sector (Bangladesh Bank 2017). In India, the RBI's Priority Sector Lending (PSL) program requires banks to allocate a large share of credit to specific sectors. In 2015, the program was extended to lending for green projects.

4. Open Questions and Research Priorities

Research on the implications of climate change for central banks is rapidly growing, and many questions remain open. Broad questions have been raised, and research priorities identified, on the subjects of monetary policy regimes, financial stability, and the coordination of different policy areas:

- **Monetary policy.** What are the implications of climate change for monetary policy regimes and frameworks? The effects of climate change and the implications for the design of monetary regimes will vary across countries (NGFS 2020a). Likewise, transition policies could have spillover effects as a result of trade or other interdependencies. Research is thus needed to understand "whether climate change may have fundamental implications for the design of monetary regimes," including the choice of the policy target, the horizon to meet the target, and the monetary strategy's degree of flexibility (NGFS 2020a). More broadly, does climate change require a new monetary regime, e.g. centered on the economic effects of climate shocks? Given the magnitude and diversity of projected climate shocks across regions, should monetary policy analysis use as a starting point region-specific climate models? Should carbon prices have a role to play in anchoring inflation expectations and lowering the volatility of various prices?

- **Financial stability.** Given the global nature of climate-related financial stability risks, they cannot be adequately addressed only at the national level. How should these risks be addressed, and how should the relevant policies be coordinated, at the international level? A further challenge that may arise is the combination of severe financial and economic crises resulting from "Green Swan" events (Bolton et al. 2020). Against this backdrop, does climate change call into question central banks' ability to maintain both price stability and financial stability (Bernal-Ramírez and Ocampo 2020)? Should financial authorities use a precautionary policy approach to foster a regime shift toward sustainable capital allocation (Kedwards et al. 2020)? A proposed starting point could be the identification and exclusion of unsustainable activities, whose financing could be discouraged via prudential tools. Another proposal is for asset purchase programs and collateral frameworks to exclude assets linked to unsustainable activities (e.g., deforestation).

- **Policy coordination.** Is coordination of different policy areas needed to adequately address climate risks and to mitigate climate change? Given radical uncertainty around the risk channels and future impacts of climate change, should central banks put less emphasis on "improvements in risk modeling" and more on "decisive and immediate action and coordination" (Pereira da Silva 2020)? Should central banks play a coordinating role, given their potential advantage with respect to proposing new policies in the context of needed societal debates (Bolton et al. 2020)?

- **Environmental risks beyond climate risk.** It is widely acknowledged that environmental risks extend beyond climate risks (IPCC 2018, IPBES 2019). In particular, nature-related financial risks are expected to increase as anthropogenic pressures drive biodiversity losses closer to a tipping point (Kedwards et al. 2020). In this context, should coordination among policymakers extend to standard setters by considering ecological accounting frameworks (Pereira da Silva 2020)? Pereira da Silva (2020) suggests that such coordination could entail accounting standards to capture interdependencies between economic and natural systems, as well as disclosure of additional types of exposure.

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