Network for Greening the Financial System

Technical document

Climate change, the macroeconomy and monetary policy

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Foreword

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Climate change, and policies that governments implement to address it, increasingly have macroeconomic impacts over time horizons relevant for monetary policymakers.

In a 2023 NGFS survey, members expressed a need to deepen their understanding of these impacts. This is an essential step for adequately evaluating the implications for monetary policy. In response, the NGFS has produced three reports on the macroeconomic impacts of climate change and the green transition. These focus on (1) the impacts of acute physical hazards, (2) the transition to net zero, and (3) climate macroeconomic modelling.

This publication consolidates the key messages from these three reports, covering how physical hazards and the transition to net zero can influence variables such as output and inflation, and outlining how central banks could incorporate climate-related impacts in their modelling toolkits.

The reports show that both the physical and transition effects of climate change can have macroeconomic impacts over time horizons relevant for monetary policy. In addition, as the frequency and magnitude of acute physical impacts increase and as the green transition accelerates, monetary policymakers are likely to face difficult trade-offs. As such, understanding these macroeconomic effects is becoming increasingly important for central banks.

We want to thank the NGFS members, observers and the NGFS Secretariat for contributing to this work. We hope that it will assist central banks in better understanding the implications of climate change for monetary policy.

In 2022, the NGFS established the Workstream on Monetary Policy with the objective to "deepen the collective understanding of how climate change, and the actions designed to mitigate it, should be considered in relation to the conduct of monetary policy".

As a first step, it has developed a framework to assist central banks in understanding the macroeconomic impacts of diverse climate-related developments which affect monetary policy. This is set out in two reports on the physical and transition impacts of climate change, and a modelling handbook. The purpose of this paper is to summarise the key messages from these three publications.

In addition, the NGFS has separately considered how climate factors affect central banks' implementation of a given monetary policy stance. This question is different from how climate factors affect the monetary policy stance itself and is analysed in the separate publication Adapting central bank operations to a hotter world: current progress and insights from practical examples (NGFS, 2024b).

1. Motivation and the journey for central banks so far

Climate change, and the policies implemented to address it, are increasingly impacting the global economy. The UN's Intergovernmental Panel on Climate Change (IPCC) estimates that average global temperatures are now more than 1 °C higher than pre-industrial levels and are set to rise at 0.2 °C per decade, due to past and ongoing greenhouse gas emissions (IPCC, 2023). As a result, both chronic physical impacts and severe weather events are rising in frequency, intensity and geographic spread.

Current policies remain insufficient to mitigate market failures associated with climate change, which are translating into sizeable costs for the global economy. Annual global damages from weather-related hazards have more than doubled in real terms in the past twenty years and are already affecting economic activity (Banerjee *et al.*, 2023). To mitigate these impacts, over 190 countries have signed the Paris Agreement to limit global warming while enhancing their resilience. Policy actions to meet the Agreement affect economic outcomes in both the short and long term. The IPCC and the International Energy Agency (IEA) indicate that there is still a gap between policy actions announced to date and what is required to meet the pledges made under the Paris Agreement. If this gap is not addressed the physical impacts of climate change will worsen (IEA, 2023; IPCC, 2021). This could prompt governments to make major and sudden policy changes to decarbonise, which could have abrupt and large economic impacts further ahead.

Climate change and the transition to net zero will therefore increasingly affect macroeconomic outcomes at horizons relevant for monetary policy and their impact is likely to increase over time. This makes understanding these effects relevant to central banks as they seek to achieve their mandates.

Understanding the macroeconomic effects of climate change is a relatively new issue for central banks. The work of the NGFS initially focused on central banks' micro-prudential and supervisory responsibilities and subsequently on sizing and understanding the financial stability risks posed by climate, and designing scenarios to help with this. Following some preliminary exploration of climate change and monetary policy impacts (NGFS, 2020), it led work on monetary policy operations between 2019-2021 (NGFS, 2021). Since 2022, the NGFS has focused on deepening the collective understanding of how climate change, and the actions designed to mitigate it, should be considered in relation to the conduct of monetary policy. The first phase of the work has focused on understanding how climate change and the transition to net zero affect macroeconomic outcomes.

To get a snapshot of where central banks were in this journey, the NGFS started by conducting a first of its kind survey (NGFS, 2023a) to identify progress to date in this field, key gaps and challenges in order to inform its priorities. The survey highlighted that taking the impact of climate

change into account in the context of monetary policy analysis (and central bank operations) was still at an early stage. Central banks therefore had a clear desire to first better understand the macroeconomic impact of climate change and the transition to net zero, before moving to consider the implications for monetary policy decisions.

Following the survey, the NGFS committed to:

- **Support central banks in their efforts to better understand the physical impacts of climate change on their respective economies.** Such support could help to clarify what central banks need to know about the macroeconomic effects stemming from the acute impacts of climate change, capturing both domestic and international transmission channels and their relevance to monetary policy.
- **Establish a common foundation across central banks on the ways in which the net zero transition ("the green transition") might affect the economy, with a focus on the monetary policy horizon (typically around two to three years).** This involves exploring the channels through which the three major transition drivers (climate policy, technological change, and changes in preferences and public attitude), and the investment needs they generate, could affect the economy and therefore monetary policy (and its implementation).
- **Build capacity and share learnings in the construction of modelling and analytical frameworks.** Work to advance modelling toolkits and overcome common challenges was identified as critical because it underpins the ability to make informed assessments of the macroeconomic impacts stemming from climate change.

The three macroeconomic reports recently published by the NGFS aim to deliver on these commitments, by helping to bridge the identified gaps and shed light on the impact of climate change on the macroeconomy and monetary policy. The three reports can be found here:

- **Acute physical impacts from climate change and monetary policy** (NGFS, 2024a)
- **The green transition and the macroeconomy: a monetary policy perspective** (NGFS, 2024d)
- **Climate macroeconomic modelling handbook** (NGFS, 2024c)

2. Key perspectives for central banks in the context of monetary policy

It is useful to start with the context in which central banks, which focus on their primary mandate of price stability, approach understanding the macroeconomic impacts of climate change and the transition to net zero.

Central banks take as given climate science, government policy, and their respective mandates. Central banks are not the experts on climate science. Instead, they are focused on how climate change affects the economy and the financial system, and therefore the achievement of their statutory objectives. On the policies needed to mitigate climate change, it is governments, not central banks, that are in the driving seat. However, these policies will have economic impacts that need to be factored in, including where there is uncertainty about the path for these policies, as this can also affect economic behaviour. While central bank mandates across the NGFS membership vary, one key aspect that unites all central banks is that as the impact of climate change and of the policies enacted to address it increases, it becomes an increasingly relevant consideration for monetary policy.

The horizon over which climate-related shocks materialise will be an important consideration for monetary policy. The NGFS has undertaken prior work on the longer-run impacts of climate change and has published long-term scenarios that accord with different combinations of physical and transition risks (NGFS, 2023b). These climate scenarios have largely been used to assess financial sector resilience to climate-related shocks. While medium term changes in the economy are also important to monetary policymakers, they are mainly focused on shorter time horizons, typically two to three years ahead. The focus of this set of reports is therefore on what the shorter-term impacts might be and how they are modelled. Nevertheless, as the three macroeconomic reports draw out some of the challenges and trade-offs central banks might face in the near-term, it is important to keep in mind the perspective that the long-run scenarios make clear: adopting more ambitious mitigation actions earlier will lead to better long-run macroeconomic outcomes.

Macroeconomic impacts and the relevance of shocks for monetary policy will vary across economies, depending on the type of economy, the stage of development, the susceptibility to climate shocks, and the climate transition path. The work presented in this set of reports has sought to embrace that diversity, leveraging the wide-ranging experiences of the NGFS membership.

There is also an important international dimension for central banks to consider. Indeed, small open economies can be exposed to climate shocks and climate policies in other jurisdictions. For example, countries that may be less susceptible to the physical effects of climate change because of their geography can still be affected by the impact of extreme weather events abroad through trade and financial linkages. Additionally, policies implemented across countries may differ, leading to different incentives for firms on where to locate their economic activity and investment. This means that international spillovers and cross-border impacts also need to be better understood and accounted for.

2.1 Acute physical impacts from climate change and monetary policy

Physical impacts from climate change can be either chronic or acute, with acute impacts typically more prominent over the monetary policy horizon. *Acute physical impacts* result from the increasing frequency and severity of extreme climate or weather events (such as heatwaves or floods). Such events are largely unpredictable and thereby bear resemblance to other shocks that unfold over the business cycle and to which monetary policymakers tend to adjust monetary policy. *Chronic physical impacts* arise from long-term shifts in climate and weather patterns (such as rising average temperatures). While such climate impacts will mostly occur beyond the monetary policy horizon, the horizon over which these impacts are having material economic effects is increasingly narrowing as the impact of climate change becomes more proximate.

As acute physical hazards intensify, become more frequent and more geographically widespread (IPCC, 2023)**, their macroeconomic effects will become increasingly important in both the shorter and longer run.** The corresponding increase in the cost of damages is expected to stem in part from the compounding of severe weather events and the non-linear relationship between the intensity of the event and the damages caused by it.

The initial focus of the NGFS work on acute (or extreme) weather events has reflected the membership's broad-based concerns about these near-term impacts, which also pave the way for future work to focus on the possible implications for monetary policy as these shocks become more frequent and severe. Chronic impacts, while clearly relevant for understanding the longer-run equilibrium position of the economy, were not in the main focus of this work.

The report on Acute physical impacts from climate change and monetary policy makes clear that no two physical hazard events will have the same macroeconomic effects. The extent to which physical damages translate into economic and financial ones will depend on: (1) the nature and type of the hazard; (2) the level of economic activity at the location where it occurs; and (3) the vulnerability of assets and economic activity to physical events, reflecting construction quality, preparedness and response capacity.

Moreover, the extent to which physical hazard events generate economic losses will also depend on the resilience threshold of a jurisdiction. The threshold is country-specific and will depend on a range of factors, including the structure of the economy, its stage of development, as well as its fiscal capacity and insurance mechanisms.

The supply side of the economy is often where the immediate impact of physical hazards is first experienced as current and future production of goods and services are impaired or may even come to a complete stop. These effects materialise through impacts on the standard determinants of production: (1) *capital*, through the physical destruction of goods, productive capital, and real estate and infrastructure; (2) *labour*, *via* the displacement of workers and job losses; and (3) *total factor productivity* (TFP), particularly for labour and agriculture (crop yield). Productivity can also be affected when attention and resources are devoted to reconstruction efforts after a shock.

Severe weather events and the associated destruction and loss of assets can also negatively impact the demand side of the economy through effects on household and firm wealth and income, expectations of future climate events as well as consumer and business confidence. These effects come through a variety of channels including: (1) destruction of housing and disruption of wage payments or business income as well as diminishing disposable income/net wealth (for consumption/investment); and (2) greater uncertainty about growth and income prospects that may depress consumer and business confidence, reducing investment and increasing precautionary savings.

Effective insurance mechanisms, with fast and predictable payouts, can limit the economic fallout from severe weather events and speed up the recovery process. However, research suggests that 55% of global losses from physical hazards are currently not insured and this may rise in future (Munich RE, 2024). von Peter *et al.* (2012) find that the uninsured part of catastrophe-related losses drives macroeconomic costs, whereas well insured catastrophes can be inconsequential or even positive for economic activity in the long-term.

Financial channels can amplify effects through asset prices as well as *via* credit conditions and credit volumes. Tighter financial conditions and reduced access to finance can slow down the recovery and may result in spillovers to initially unaffected areas of the economy. A reduction in asset prices associated with the destruction of physical assets can negatively impact the value of the collateral that borrowers can pledge to secure a loan, which in turn weakens the balance sheet of financial intermediaries. If banks' balance sheets are adversely affected, it can affect their willingness and ability to lend, which can be particularly problematic given the increased demand for recovery loans in the aftermath of a disaster.

Looking at the impacts on the key aggregate macroeconomic variables of interest to central banks, econometric studies tend to find negative impacts on GDP from severe weather events both in the short- and long-term. In the immediate aftermath of such an

event, both the level and the growth rate of GDP drop. Depending on the study, GDP growth rates decline by more than 0.5 percentage points in the year of the shock for severe events and reach significantly higher values for the worst events. Over time, GDP growth recovers, but for severe disasters, GDP can remain significantly below its pre-shock level 20 years later.

Emerging market and developing economies (EMDEs) have experienced a larger economic impact following a disaster of similar magnitude, likely reflecting their lower resilience threshold relative to advanced economies (AEs). For example, one study has found that a climate disaster results in a cumulative per capita output loss of 0.25%, 0.5% and 1% for high, middle, and low-income countries respectively (Raddatz, 2009).

International spillovers from severe weather events can be of considerable magnitude, and mainly occur through commodity prices. In a panel of 75 countries, de Winne and Peersman (2021) show that a 10% increase in global food commodity prices stemming from weather shocks lowers GDP by 0.5% after six quarters. The impact is stronger in AEs since they tend to be net importers of agricultural products.

The effects on inflation of a specific severe weather event depend on whether the demand or the supply effects of the event dominate, in addition to the type of disaster, the sectors exposed, the structure and maturity of the economy, location, seasonality, and time horizon. For example, in the short term, storms increase food price inflation, while floods increase headline inflation (Parker, 2018). Overall, the inflationary effects can also be nonlinear, as documented in the case of heatwaves. In AEs, the effects on inflation tend to be smaller, while EMDEs can experience elevated inflation for several years following an extreme weather event (Parker, 2018). Moreover, Peersman (2022) documents how shocks to international food prices can spill over into domestic inflation even if the shock originated abroad.

Fiscal policy and related targeted government support measures play a key role in helping households and businesses to navigate the impacts of such shocks.

Looking ahead, monetary policy is also likely to be affected by the increase in the frequency, severity and geographic coverage of severe weather events. Where inflation expectations are well anchored, the textbook monetary policy response to (supply) shocks, such as these, has been to look through the first-round effects on inflation, particularly if judged not to be persistent. However, this is less clear cut when shocks are larger, more frequent or have more persistent effects, exacerbating the trade-offs facing monetary policymakers. Such increased inflation/output trade-offs could further exacerbate challenges associated with the communication of monetary policy, in particular for inflation-targeting central banks, when greater and persistent inflationary pressures from severe weather events call for policy tightening against the backdrop of an extensive decline in supply.

Monetary policymakers will also need to consider the long-term implications of physical hazards for potential output and growth, and the appropriate longer-run stance of monetary policy. Going beyond the effects of a specific event, the changes in the distribution of severe weather events – an increase in the frequency, intensity, and geographic spread of physical hazards – will alter the investment and savings behaviour of economic actors globally with implications for important policy determinants such as the long-run neutral rate of interest, and for central bank communications.

2.2 The green transition and the macroeconomy: a monetary policy perspective

Governments around the world are responding to the threat posed by unmitigated climate change by setting targets and introducing policies to reduce greenhouse gas emissions and to deliver the transition to net zero. As of 2023, 195 nations have committed to the Paris Agreement (UNFCCC, 2024), and more than 130 countries (representing over 90% of global GDP) have adopted net zero GHG emissions targets (OECD, 2024). Many AEs have pledged substantial emissions cuts by 2030 and net zero by 2050, while the climate targets of many EMDEs are typically beyond 2050 (Climate Action Tracker, 2024).

The objective of the report on The green transition and the macroeconomy: a monetary policy perspective is to provide central banks with a basis upon which the macroeconomic effects of the key drivers of the transition – climate change mitigation policies, technological change, and changes in preferences – can be better understood.

While governments are the main actors in setting the policies to deliver the transition, it is important for central banks to better understand the macroeconomic effects of the transition in order to adequately account for these in their macroeconomic assessments and decision-making. Government commitments and policy actions may typically extend beyond the monetary policy horizon. However, the actions designed to meet them are being taken now, with macroeconomic effects beginning to materialise over the monetary policy horizon. In addition, economic agents may anticipate future effects to come, influencing the behaviour of consumption and investment now.

According to the IPCC and the IEA, a substantial gap remains in the emissions reductions embodied by current policies and what is needed to achieve the goals of the Paris Agreement. This implies that further policy action by governments will be required to achieve the pledged commitments (IEA, 2023; IPCC, 2023). From a macroeconomic perspective, in addition to the impacts associated with climate change mitigation policies and the other transition drivers, this gap in policy action has the potential to generate uncertainty about the transition pathway that can in turn have macroeconomic effects (e.g. *via* affecting planned investment).

While the transition might give rise to some trade-offs for policymakers to manage in the near-term, the macroeconomic impacts from climate inaction or delayed action – *via* more severe and frequent physical damages – will be significantly larger (NGFS, 2023b). For instance, Mehrhoff (2023) finds that an orderly net zero transition by 2050 could result in global GDP being 7% higher relative to a scenario with no transition.

The key aim of climate change mitigation policies is to help facilitate major structural changes within economies by shifting consumption patterns and production activities towards low-carbon alternatives, and by scaling up investments to facilitate the transition. As part of this "green transition", large-scale investments in renewable energy and other green technologies will be necessary, alongside higher rates of innovation in such technologies as well as changes in preferences. Policies broadly fit into three buckets: (1) carbon pricing; (2) government subsidies and government investment; and (3) non-market-based climate policies, regulations and standards.

The green transition will affect the behaviour of households, firms and investors in the economy and will have implications for government spending and revenues. Changes in consumer prices, wages, and asset prices associated with the transition will affect household income, wealth and saving patterns. For households, there are also development co-benefits of climate action, such as direct improvements in human health or reductions in congestion and accidents. For firms, investment decisions will be influenced by transition policies aimed at shifting production and investment towards low-carbon activities, as well as by changes to costs, technological innovation, preferences, productivity and profits and the financing conditions they face. For governments, carbon pricing will generate revenue whereas subsidising green technology will need to be financed by debt issuance or taxes, with implications for fiscal and macroeconomic outcomes. Fossil-fuel exporters will face a more challenging transition, while economies endowed with critical minerals could benefit from new opportunities. The co-benefits of climate action on citizens' health and the reduction in congestion and accidents have shown to have a positive impact on government fiscal balances given the aggregate improvements in public health and associated reduction in health spending, especially in EMDEs where air pollution has detrimental impacts in some cases.

Financial feedback effects can amplify macroeconomic impacts, with expectations playing a crucial role. The transition will create challenges and opportunities for banks and investors as they reallocate capital. Carbon-intensive firms may experience negative impacts on their future profitability, asset valuation and credit conditions. On the other hand, low-carbon firms are likely to see the opposite effect as banks and investors reallocate capital away from carbon-intensive industries. Changes in investment flows can cause volatility in financial markets and affect the valuation of a wide range of assets.

Overall, the transition is likely to increase inflation in the short term, while the short-term impacts on output are more ambiguous. In the short-run, factors such as increasing carbon prices, stringent climate regulation and shifts in consumer demand can increase firms' costs and put upward pressure on inflation. However, other factors, such as technological innovation can reduce costs and dampen inflationary pressures. The impact of higher green investment on overall output will depend on (i) whether investments are additional or merely redirected from other section; (ii) the multiplier effects on economic activity, and; (iii) the impact on consumption.

Different types of climate policy levers will have different impacts even where policies have comparable effects in terms of emissions reductions. The effect on inflationary pressures will depend on the balance between the impacts on aggregate supply and demand. The net effect on inflation will additionally depend on the response of monetary policy. There is a burgeoning literature exploring these effects, where the assumptions underpinning the analysis can play an important role in determining the results:

- **In the short-run, carbon prices might look like negative supply shocks**, pushing up headline inflation and dampening output. However, the medium-term effects will largely depend on the policy design, including how carbon tax revenues are used, as well as how policies affect the expectation formation of different agents.
- **The short-run impact of green subsidies will depend on who receives them.** A green energy subsidy for households could be deflationary in the near term, while an increase in demand pushes output up. On the other hand, an investment subsidy may push up aggregate demand as well as inflation. In the longer run, a crucial determinant is also how the subsidy is financed.

When assessing the aggregate impacts of different climate policy approaches, there is an important dependency on whether other supporting and complementary policies are deployed as part of the broader policy mix and the wider policy environment, including the degree of policy certainty and credibility.

Climate change mitigation policies also have the potential to generate significant international spillovers and cross-border effects. As policies will vary in stringency and coverage across countries, this can generate competitiveness impacts and potentially give rise to changes in trade patterns and domestic production. These differences and concerns around effects on competitiveness have seen some countries decide on the need to take further action – for example, the use of Carbon Border Adjustment Mechanisms (CBAMs). Differences in policy approaches may also impact balance of payment positions and exchange rates, particularly in economies where a larger share of economic activity stems from carbon-intensive sectors. Furthermore, whilst many EMDEs may stand to gain by developing new areas of competitive advantage for green trade, they also face challenges from the slow diffusion of green technology and the lack of financing for green energy investments.

Lastly, the green transition will not necessarily be smooth and linear, which could result in short-term volatility in inflation and output. Disruption to economic activity could arise from multiple sources, including unexpected policy changes and policy uncertainty, non-linear technological advancements and sudden changes in consumer and investor preferences. Such shocks could be amplified by financial feedback effects through the credit and asset price channels. Potential supply-demand imbalances during the transition in energy and critical minerals or skilled labour could also induce short-term volatility in inflation and output.

For central banks, the findings of this report highlight the importance of understanding the macroeconomic impacts of the green transition and the impacts on the channels relevant for monetary policy. As with any economic change, monetary policymakers will need to distinguish between temporary and permanent effects, and between supply-side and demand-side impacts. Transition-related impacts, and the associated uncertainty, are expected to be complex and willrequire central banks to adjust their approach to policymaking and communication. Moreover, the direction and magnitude of the impacts of the green transition on the longer-term structure of the economies and the natural interest rate will ultimately require empirical work and further exploration.

2.3 Climate macroeconomic modelling handbook

To understand and assess the macroeconomic impacts of climate change and the transition, economists are developing and adapting climate macroeconomic models. The NGFS membership survey conducted in 2022 highlighted that the majority of central banks had not formally included climate considerations into the forecast models that support their monetary policy committees' decisions (NGFS, 2023a). Moreover, central banks identified several challenges and uncertainties associated with modelling these impacts. These included data quality and availability, questions over how to integrate climate and macroeconomic models, on how to capture uncertainty effects, and on exploring linkages across sectors and the need to improve supply-side modelling.

In response to the feedback and challenges identified by its membership, the Climate macroeconomic modelling handbook has been developed by the NGFS to provide technical guidance to central banks and supervisors drawing on an in-depth survey of the work done by academics and policymakers on these issues.

The handbook distinguishes between the modelling approaches used to assess the macroeconomic effects of physical and transition impacts. It is tailored to help members at different levels of development and engagement – whether they are beginning to consider climate-related modelling or whether they have already begun efforts and are in the process of choosing next steps.

Modelling the physical impacts of climate change requires the integration of two disciplines: climate science and economics. The dominant type of models used in the field are Integrated Assessment Models (IAMs) that combine climate and economic modules to understand the effects of climate change in the economy specifically *via* the use of a "damage function". The damage function relates the physical impacts of climate change to economic variables using a climate stressor (which is usually temperature change).

The macro module underpinning the IAMs can either take the form of a computable, general equilibrium (CGE) or Dynamic Stochastic General Equilibrium (DSGE) model. Which macro basis to use will depend on the question the researcher is trying to answer. If the researcher wants to understand the effects of higher frequency, acute climate events – which as highlighted in the report on Acute physical impacts from climate change and monetary policy, can be of more imminent relevance over the monetary policy horizon – it is often better to use IAMs based on a DSGE structure, since they are better equipped to deal with stochastic events. Incorporating a natural disaster event into an existing model used by the central bank can be a relatively straightforward way to highlight two of the most important transmission channels from acute physical shocks: the destruction of physical capital and the decrease in TFP. On the other hand, to understand and model chronic impacts, the guide suggests researchers favour IAMs based on a CGE structure that assumes perfect foresight. This is useful because the simplification gained by dropping uncertainty allows the researcher to include other features, such as non-linearities, or more layers of sectoral and geographical disaggregation.

In the context of modelling the impacts from the transition, the handbook explores the macroeconomic dynamics that arise during the phasing out of fossil fuels and the adoption of more energy efficient and less polluting technologies, often motivated by changes in polices (carbon pricing, regulation, etc.). The work highlights the importance of including the assumption that firms cannot easily substitute among production inputs, at least in the short term. It further delves into the importance of including more realistic production structures when modelling the supply side, in which consumption and investment goods are made using intermediate both green and emissions intensive inputs. This points to a need for sectoral economic modelling, which is relatively uncommon in central banks.

From a practical perspective, the handbook also considers how to make use of existing models. For example, policy-related transition impacts can be modelled using relatively conventional models such as those used to assess the impact of taxes and subsidies. Though the interactions between domestic policies, divergence in stringency across

trading partners and the potential lack of predictability of policies can pose additional challenges.

A common theme cutting across both the modelling of physical and transition impacts is uncertainty. For physical impacts, the key uncertainty is about natural processes and how they interact with our economies. Here the challenge is improving the modelling of possible macroeconomic impacts resulting from non-linear changes in the climate system that are not yet accounted for, such as rising sea levels or the crossing of climate tipping points. For transition impacts, there is uncertainty on how new technologies may accelerate changes in industries and the speed of convergance towards net zero. But perhaps more important, both firms and households face political uncertainty about whether climate change mitigation policies may be reversed.

Modelling climate change is difficult, and while toolkits have been improving, there is no "silver bullet" or single model that can answer all questions. Different research questions will require different approaches. Central banks should confront these challenges not as a standalone project, but rather as a research agenda that gradually incorporates and adapts different models into a broader analytical toolkit.

3. Monetary policy implications and next steps

The first phase of work conducted by the NGFS under the Workstream on Monetary Policy has demonstrated that climate change and the transition to net zero are increasingly having macroeconomic effects at the horizon of interest to monetary policymakers. These impacts can arise from both domestic physical events and climate policy choices, but also through cross-border and spillover effects following overseas events and policy decisions given international linkages.

In terms of acute physical impacts, the literature is clear that extreme weather events tend to result in increased volatility and lower output in the short run, while the impact on inflation will depend on how supply and demand are affected and the response of monetary policy. In the short-term, prices are likely to rise because of disruptions to food and goods supplies and, furthermore, the disruption to global supply chains for these goods could create spillover effects in other countries too. While many of the studies examined cover periods when the shocks were likely smaller and relatively infrequent, it is clear that climate shocks are increasing in both frequency and magnitude.

While monetary policy has typically looked through the first-round effects of these types of events, where inflation expectations are well anchored, as the trade-offs become more persistent – for example because of repeated and more extreme events – doing so may become more challenging.

Climate transition policies vary in their macroeconomic impact, with some materialising similarly to negative supply shocks, while others may present similarly to demand shocks, requiring different considerations for the response of monetary policy. Moreover, how policies are implemented will also have macroeconomic implications. For example, on the one hand given the gap between announced pledges and enacted policies, it is possible that policy action will increase over a number of years. But it is also possible that action is more delayed and then comes more rapidly than expected. The latter would create larger and more disruptive movements once policy action is implemented. In either case, monetary policy may need to deal with a large and prolonged relative price shock. In addition, depending on the policy adopted, output may fall, at least in the short run, again giving monetary policymakers a difficult trade-off to manage.

Climate change and the transition may also impact on the long-run equilibrium real interest rate (R*). On the one hand, there are a range of factors that could push R* up. For example: the rise in green investment for decarbonising industries; an increase in productivity growth from green innovations; an increase in government debt associated with green subsidies or public investments deployed to decarbonise, or; public spending/investment associated with infrastructure reconstruction and adaptation measures. On the other hand, there are a range of factors that could push R* down. For example: a reduction in non-green investment; an increase in precautionary saving in response to increased transition risks; an increase in risk premium from higher macroeconomic volatility/uncertainty, or; riskiness of green investments. At the same time, more severe physical impacts could be associated with lower productivity growth and higher depreciation of capital assets.

Central banks have been developing their analytical toolkits to understand the macroeconomic impacts from climate change and the transition. The key message is that we cannot let the best be enemy of the good: the direction is clear but the accuracy challenging to achieve given many uncertainties and further progress needs to be made where possible. On physical impacts, combining two disciplines – science and economics – is complex and at an early stage, while for modelling transition impacts, there is a role for central banks to make use of existing models, such as those used to model the effects of taxes and subsidies in the near term. A key next step in this regard will be supporting members to practically embed these tools into their regular analysis and forecasting processes.

Central banks have different mandates and responsibilities in the context of climate change, but every institution needs to understand the macroeconomic shocks and forces shaping their economies, which are likely to differ across jurisdictions. If, for example, the physical shocks become bigger and more

frequent, then it will become harder for monetary policy to simply "look through", so it is necessary to understand the impacts and how to respond. Equally, in the context of the transition, central banks will need to understand the extent to which price changes in the economy reflect the relative price adjustment required to deliver the transition versus generalised price pressures. Moreover, the balance between physical and transition impacts, as well as the specific shocks within each dimension, will be idiosyncratic to each economy. As the NGFS moves forwards to consider implications from climate-related changes for monetary policy strategy, building on the analytical foundation laid by these three macroeconomic reports, the next phase of work will continue reflecting on key questions such as:

- How should central banks approach repeated and/or more persistent climate-related shocks?
- How should central banks account for climate-related uncertainty?
- Are the shocks generated by climate change and/or climate transition like any other or are they unique? Which aspects of such shocks share commonalities with other macroeconomic shocks central banks are familiar with?
- What are the implications for R*?

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