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Inflation and climate change: the role of climate variables in inflation forecasting and macro modelling

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Summary

Climate change is increasingly affecting the objective, conduct and transmission of monetary policy. Yet, climate-related shocks and trends are still generally absent from the canonical models used by central banks for their policy analysis and forecasting.

This briefing paper reviews the potential pitfalls of using a modelling framework that omits climate-related information and provides some reflections on how central banks can integrate climate change considerations into their 'workhorse' models. This includes: accounting for an explicit role of the energy sector in the production structure and for specific climate change policies; improving the ability of models to cope with various sources of heterogeneity; and incorporating a more realistic representation of the financial sector, to analyse the possible stranding of assets and impairments in the transmission mechanism of monetary policy. It argues that a 'suite-of-models' strategy is a promising approach for central banks to cope with the climate challenge when designing a new generation of models.

To complement theory with practice, several examples of central banks that have already integrated climate-related information into their analytical frameworks are provided. The paper concludes with some specific recommendations.

This paper is part of a toolbox designed to support central bankers and financial supervisors in calibrating monetary, prudential and other instruments in accordance with sustainability goals, as they address the ramifications of climate change and other environmental challenges. The papers have been written and peer-reviewed by leading experts from academia, think tanks and central banks and are based on cutting-edge research, drawing from best practice in central banking and supervision.

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1. Introduction

Macroeconomic models play an important role for the conduct of monetary policy in central banks. They are used for a variety of purposes, including forecasting, scenario analysis, and to design, evaluate and communicate central bank policies. Model-based forecasts of inflation, for example, are a key input for policy decisions at inflation-targeting central banks, which calibrate their monetary policy instruments in a forward-looking manner to ensure that inflation returns to its target over the medium term.[1]

Models used at central banks differ in many aspects, depending on the characteristics of the economy, the purpose of the analysis, and policymakers' needs. While some models are optimised for forecasting performance, others are more structural, with foundations derived from economic theory.

A common feature of the macroeconomic models currently used by central banks is that they typically abstract from aspects related to environmental degradation, such as climate change and biodiversity loss. Yet, a growing body of literature documents that these trends are increasingly affecting the objective, conduct and transmission of monetary policy (Boneva et al., 2021; NGFS, 2021d). Notwithstanding the importance of broader aspects of environmental degradation for macroeconomic stability and the conduct of monetary policy, the focus of this briefing paper is on the risks and trends related to climate change, a conventional starting point that has featured more prominently in the literature so far.

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The more frequent occurrence of highly destructive, extreme weather events observed globally in recent years has increasingly challenged the notion that such events are mainly a concern beyond the typical price stability horizon of central banks. For example, frequent droughts, heat waves and floods may lead to upward pressure on commodity and food prices, and hence on inflation (Batten et al., 2020). The stranding of assets and sudden repricing of climate-related financial risks could generate losses in the financial system and impair financing flows to the real economy, affecting the transmission of monetary policy. There is also concern about possible 'green swan' catastrophic events (Bolton et al., 2020), which may cause major economic disruption and may occur with little warning.

Following decades of procrastination, the green transition seems finally to be gathering pace. In most scenarios, it will imply sizeable changes in the level and volatility of energy prices, an accelerated obsolescence of the existing capital stock, significant reallocation of labour and capital, and a strong acceleration in investment. Such developments will have major implications for monetary policy. The challenge for monetary policy will be particularly acute in a disorderly transition. But the scale of the required transformation is such that its effects will also be felt in an orderly scenario spread over decades.

In addition, climate change will complicate the assessment of the stance taken by monetary policy – as a source of more frequent, intense and persistent shocks to the economy, whose nature (supply and demand) will be harder to identify. As a consequence, climate change will increase the prevalence of output and price stabilisation trade-offs, also as uncertainty may compound the effects.

Against this background, it is essential to better understand the implications of climate-related risks for monetary policy. This implies a need to strengthen the economic analysis of climate change, develop new statistical indicators and improve central banks' macroeconomic models. This paper offers some suggestions about how this can be accomplished. Section 2 reviews the main issues with a modelling approach that ignores climate change. Section 3 makes the case for integrating climate change considerations in central banks' macroeconomic models and

[1] According to IMF (2021a), there are currently 43 countries that use inflation targeting.

discusses some possible options for how this could be done. Section 4 presents some concrete examples, highlighting lessons learned. Section 5 concludes with recommendations on the best way forward.

2. Issues with macroeconomic models that ignore climate change

Given the recurring and persistent effects of climate change and related policies on the economy, projections and scenario analyses based on the current generation of macroeconomic models that omit climate-related information are likely to be inaccurate. Below we discuss the main limitations of the current generation of models while some concrete options for how these limitations can be overcome are presented in Section 3.2.

First, the workhorse models currently used by central banks do not include a consistent analytical framework linking climate and macroeconomic outcomes.[2] This is a problem as they cannot account for the different transmission channels through which physical and transition risks may affect output, potential output, inflation and other variables of interest for setting the most appropriate stance for monetary policy (ECB, 2021).

Second, the energy sector is modelled simplistically, often only through oil, and the production structure does not explicitly account for the role of energy as an input factor and for specific climate change policies. Sustainable forms of energy are also currently not considered. Distinguishing among various forms of energy generation is important, as different forms of energy have different carbon intensities and are thus differently exposed to transition and carbon policies (ibid.).

Third, heterogeneity is largely absent in central banks' modelling effort, e.g. geographically and across sectors and industries. This is problematic when modelling climate change, as small changes at the aggregate level can conceal large divergences at a more granular level. For example, transportation and manufacturing would be affected differently by changes in carbon prices. These changes across sectors can have macroeconomic implications (McKibbin et al., 2020).

Fourth, models of the current generation do not encompass a financial sector that distinguishes between different forms of financing, e.g. to allow risk premia on green and polluting investment to be separately determined. In turn, it is important to assess the role that financial markets can play in funding the green transition and to examine the impact of the transition on the transmission mechanism of monetary policy (ECB, 2021).

Fifth, forecasting and nowcasting models do not make use of meteorological or carbon pricing data, despite evidence that including such information significantly improves their performance (Huurman et al., 2012; Gourio, 2015), as discussed in more detail in the next section.

Sixth, not all macroeconomic models allow for global interlinkages, either real or financial. Explicitly acknowledging the global dimension of climate change in macroeconomic models is important as, even for the largest economies, the bulk of emissions will always come from the rest of the world. Hence, no single country acting in isolation will be able to significantly influence global warming outcomes if its actions are not accompanied by a collective and coordinated effort by all polluters at the global level. Moreover, climate-related shocks can transmit globally via trade and financial channels.

Prevailing information gaps and limitations in the availability of climate-related data have until recently prevented a major leap forward in modelling climate change. These are now being addressed, with a proliferation of initiatives taken by actors from both the public and the private sectors, aimed at improving data coverage and availability (e.g. OECD, 2021; IMF, 2021b).

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[2] Examples of macroeconomic models used at central banks include time-series models used for short-term forecasting and nowcasting (Banbura et al., 2010), large-scale semi-structural models (Brayton et al., 2014) and structural models of the Dynamic Stochastic General Equilibrium type (Burgess et al., 2013).

3. Climate-proofing macroeconomic models

3.1. Making a case for integrating climate change considerations in macroeconomic models

The literature has identified several rationales for why central banks have a clear interest – in some cases even an obligation – to assess the impact of climate change for the conduct of monetary policy (Boneva et al., 2021). A case for integrating climate change considerations into central banks' macro-econometric modelling can be related to these rationales, which in turn depend on the formulation of central banks' mandates.

On the one hand, climate change may hinder the ability of central banks to deliver price and financial stability in the future. Therefore, independently of their specific mandate, taking no action is generally not viewed as a sustainable option for central banks (NGFS, 2021b, 2021c). Indeed, the Network for Greening the Financial System reports a broad consensus among its members that central banks should, at the very least, adopt measures to protect their operational frameworks against climate-related risks to safeguard the smooth conduct of monetary policy (NGFS, 2021b). However, a consensus is yet to form on the type of climate-related protective adjustments that would be optimal from a central bank perspective.

On the other hand, the mandate of various central banks obliges them to support the general economic policies of their respective governments, in some cases subject to the requirement that such actions do not prejudice the price stability mandate (Dikau and Volz, 2021). Climate change has emerged as a key policy priority globally, and in line with this objective, central banks can decide to support this endeavour, for example by looking at how climate considerations can be integrated into their operations (NGFS, 2021b). In this regard, central banks could consider proactively designing monetary policy operations with green features, to support the climate objectives of their respective governments, in line with the banks' mandates.

Regardless of whether a central bank is adopting protective or proactive measures, incorporating climate change considerations into central banks' macroeconomic models and analysis would support the design of such policies, allowing assessment of their effectiveness and highlighting potential trade-offs with price stability and other policy objectives pursued by the central bank.

A growing literature has emerged on the policy options available to central banks to respond to climate change (NGFS, 2021b; Boneva et al., 2021). Some measures are more controversial as they entail an active involvement of the central bank in the allocation of credit and financial flows in the economy, an action with a political dimension pertaining more naturally to elected politicians, who are responsible to their voters. These measures include outright exclusion of certain assets deemed more polluting from monetary policy operations (e.g. from eligibility as collateral for refinancing operations or for central bank asset purchases in so-called quantitative easing programmes). Such measures involve complex trade-offs that have to be assessed on a case-by-case basis, depending on the central bank's mandate, the institutional setting and societal preferences. Improving the modelling infrastructure, which is generally regarded as supporting central banks' mandate, does not raise legitimacy concerns. Incorporating climate change into 'workhorse' models used for policy analysis (see next section) is therefore likely to be on the agenda of all central banks, including those that are not currently considering active use of their monetary policy tools to support mitigating climate change and fostering the transition to a low-carbon economy.

A swift upgrade of the macroeconomic modelling infrastructure used by central banks is necessary to better monitor and assess the evolving macroeconomic risks and to support monetary policy decision-making in a challenging environment. Central banks need to improve their understanding of the impact of climate change on activity, inflation, financial stability and the monetary policy transmission mechanism, as well

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as central banks' balance sheets. A better understanding of the costs of insufficient policies is also needed from a monetary policy perspective and could be used as an external communication device to support the transition to a low-carbon economy.

However, at present, a disconnection exists between climate-specific models such as the Integrated Assessment Models (IAMs) and the macro-econometric models used by central banks for policy analysis and forecasting. The climate-specific models that are currently used or integrated in economic frameworks are rich in terms of sources of climate-related risks but tend to represent the economy in a highly simplified way. Conversely, the macro-econometric models used by central banks incorporate a great deal of sectoral detail on the economy but lack climate-related forces and are operated to generate projections over horizons that are generally shorter than those that are relevant for climate analysis. These two strands of literature, which have developed largely independently of each other to date, need to be bridged. The next section discusses two approaches to achieving this.

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3.2. A suite of climate models as a hedge against climate-related risks

Accounting for physical and transition risks of climate change in macro models is a challenging task. Although some of the processes are well understood by climate scientists and adequately captured in climate models, integrating these aspects into macroeconomic models is difficult. While macroeconomic models are usually designed to study business cycle fluctuations where the economy fluctuates around a stationary equilibrium, global warming and the transition towards a low-carbon economy will induce a structural change over the long term. In addition, there is fundamental uncertainty regarding the future course of climate change risks and policies and how exactly they will affect economic outcomes.

Whatever the challenges, it is crucial to make progress on bridging climate-specific models and macro models used by central banks. As explained in Section 2, models lacking a representation of climate change are ill-suited to guide policymakers in a world that is rapidly warming and transitioning towards a low-carbon future.

Bridging climate-specific and macro models used by central banks: the suite-of-models approach

Many central banks rely on structural or semi-structural macroeconomic workhorse models to produce forecasts and scenario analysis, often supported by less structural time-series models to provide nowcasts or as a cross-check of the forecast.[3] In the near term, central banks can climate-proof their forecasting toolkit by making use of a suite of climate models that capture different aspects of climate change. For example, time-series models commonly used for forecasting and nowcasting can be upgraded with climate-related data, improving their forecasting performance in particular for food and energy prices (Batten et al., 2020; Bloesch and Gourio, 2015; Huurman et al., 2012).

In addition, integrated assessment models (IAMs) can be used to assess the impact of climate change on key macro variables in the longer term (Nordhaus, 2008, 2017). IAMs use insights from a range of different academic disciplines and incorporate climate, energy and economic modules. For example, they can be used to simulate a cost-effective path for the macroeconomy to meet a given climate or emissions target (ECB, 2021; NGFS, 2021a). However, IAMs face limitations in their use as they typically ignore business cycle dynamics as well as nominal and financial market frictions that are important for assessing the effects of monetary policy. In this sense, they can support and integrate the assessments based on structural and semi-structural models but cannot substitute for them. Another drawback of IAMs in practice is the sensitivity of the results to assumptions about the damage function and discount factor (for a discussion, see e.g. Weitzman, 2012). Finally, concerns have been raised about the ability of IAMs to generate climate dynamics consistent with climate models (Dietz et al., 2021).[4]

[3] An example of a structural model is the Bank of England's Dynamic Stochastic General Equilibrium (DSGE) COMPASS (Burgess et al., 2013). An example of a semi-structural model is the Federal Reserve Board's FRB/US model (Brayton et al., 2014).

[4] See also NGFS (2019) for a discussion of how other types of models, such as computable general equilibrium (CGE), agent based (ABMs), stock-flow consistent (SFC), network and overlapping generation (OLG) models, could also be used to assess the economic impact of climate change.

When used for forecasting or scenario analysis the workhorse model is typically combined with insights obtained from the suite of models. For example, when analysing the effect of coordinated global policy action in the form of carbon taxes and related policies on energy prices and domestic inflation, the path of future inflation could be generated by a model where carbon policies and ideally also the energy and agricultural sector are modelled in more detail.

In that sense, the suite of models fills the gaps of the workhorse model when it comes to climate change. To play that role well, the suite of models covers a huge range of different frameworks and ways of thinking about the economy and climate change. Different models can be selected from the suite, depending on what insight is required. Besides covering for missing channels in the workhorse model, the suite can be also used to cross-check the forecast or scenarios produced by the workhorse model or expand it to cover more variables: to key energy commodities, for example.

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Integrating climate change modules into the workhorse models

However, over the longer term, climate change considerations should be integrated in the workhorse model. For example, the workhorse model could be of the Dynamic Stochastic General Equilibrium type, accounting for both monetary policy and climate change (policy) and interlinkages between the two.[5] Alternatively, that model could be a semi-structural model augmented with modules to capture the effect of climate change and related policies as well as commodity markets and other sectors that will be profoundly affected by climate change.[6] ECB (2021) and McInerney (2022) review how the transmission mechanism of key climate-related risks can be incorporated into structural macroeconomic models.

Accounting for the impact of carbon policies or green innovation on the supply side of the economy requires modifications to the production function. For example, this can be accomplished by allowing carbon taxes to affect total factor productivity (OECD, 2017) or by including various types of fossil fuels with different carbon intensity (e.g. gas, oil, carbon) and renewable energy as separate factors of production (NIESR, 2021). Frictions can be introduced to model the limited substitutability between renewable energy and fossil fuels (McInerney, 2022). This would allow generating transition scenarios where the share of clean energy production increases abruptly when certain thresholds of carbon pricing are crossed, or when a technological breakthrough reduces the relative cost of renewables sources.

Carbon taxes and a shift in consumer preferences towards more sustainable goods and services also affect consumer prices via the demand side of the economy, similar to other indirect taxes. In addition to transition risks, physical risks should also be incorporated into macroeconomic models used at central banks. Even if a specific country does not have a high exposure to extreme weather events, physical risks can be transmitted internationally though trade channels and macro-financial linkages. International spillovers arising from both extreme weather events and international heterogeneity in climate policies are particularly important for small open economies.

Depending on the degree of granularity, central bank models that account for climate change will also require more comprehensive information on carbon footprint and the climate exposures of banks, securities' issuers and debtors. A better understanding would also be needed of the role of (private and public) insurance mechanisms to address climate change, or the lack of insurance, and their possible interaction with monetary policy.

The suite of climate models should remain a permanent feature of the forecasting infrastructure, even if climate risks, trends and policies are featured in the workhorse model. Insights from, for example, IAM models with detailed interactions between the climate and the economy can be combined with those from the structural

[5]A novel generation of general equilibrium models, many of the stochastic and dynamic type, are incorporating physical and transition risks (so-called E-DSGE models) (ECB, 2021). The literature that combines monetary policy and climate-related policies is still in its infancy but notable contributions include Annicchiarico and Di Dio (2015) and Economides and Xepapadeas (2018, 2019).

[6]Examples of semi-structural models without climate modules used by central banks include FRB/US (Brayton et al., 2014) and ECB-BASE (Angelini et al., 2019).

[7]Barnett et al. (2021) distinguish between three different sources of uncertainty:
(i) risk or uncertainty that is inherent in stochastic models,
(ii) ambiguity or uncertainty that arises as multiple models give rise to different policy implications, and
(iii) misspecification or uncertainty that arises because a model is necessarily an abstraction of reality.
One important source of misspecification when integrating climate modules in macro models is that macro models are linear or linearised, while climate change is characterised by non-linearities and tipping points.

[8]NGFS (2021e) illustrates how the suite-of-models approach can be put to work integrating an IAM and a global structural model such as NiGEM.

macroeconomic model. Also, using a wide range of models is a hedge against ambiguity and model misspecification that specifically matters when dealing with climate change (Barnett et al., 2021).[7] For example, the type of comprehensive model usually used by central banks is ill-suited to the study of structural transformations like the transition towards a low-carbon economy. Therefore, to account for climate-related risks, a prudent modelling strategy for a central bank is to make use of a suite of models, whereby the output of a wide range of models is fed into the workhorse model.[8]

Scenario analysis

In addition, central banks should make use of scenario analysis to assess how climate-related risks affect the macroeconomy in the very long run, while at the same time acknowledging various dimensions of uncertainty associated with analysing climate change (ibid.). These scenarios are informed by judgement and a suite of models and can be used to communicate dimensions of uncertainty that are absent when relying on a projection. Such scenarios have been developed, for example, by the NGFS (2020a).

The use of climate scenarios by central banks stems from acknowledging the limits of standard macroeconomic forecasting tools and the deep uncertainty associated with climate change. Unlike usual quantitative risk assessments, the future evolution of climate-related risks cannot be extrapolated from historical data, as most of the climate-related risks have not yet been observed. Scenario analyses are one way to address this shortcoming of standard models. Typically, climate scenarios describe the social, economic and policy pathways compatible with a given trajectory of greenhouse gas concentration, or they illustrate the degree of atmospheric warming implied by such a trajectory. Thus, instead of focusing on the best predictions of future outcomes, scenario analyses provide a way for central banks to compare different possible outcomes, where uncertainty is brought into the picture through a set of assumptions that can be modified in order to assess the variety of plausible outcomes. The alternative drivers of climate-related scenarios can relate to environmental conditions, longer-term physical effects, transition policies, technology and consumer preferences. They translate into shocks related, for example, to capital destruction, different levels of carbon taxation, changes in energy and food prices, technological progress or energy demand.

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A well-known set of scenarios that can be used for macro-financial analysis has been developed by NGFS (2021a). The scenarios include a standardised set of transition risk, physical risk and macroeconomic variables, developed primarily drawing on existing mitigation and adaptation pathways provided by the Intergovernmental Panel on Climate Change. Some practical considerations on how these climate scenarios may be used to assess macroeconomic and financial risks were also presented in a guide (NGFS, 2020b).

Building on the NGFS scenarios, Allen et al. (2020), for example, discuss different transition pathways, including a baseline scenario – based on an orderly transition scenario – and two adverse scenarios, spanning the period 2020 to 2050. The orderly transition scenario assumes that climate policies are introduced early and become gradually more stringent. The two adverse scenarios reflect different assumptions about the likelihood and timing of government actions, as well as technological developments and their spillover effects on productivity. These scenarios are used to illustrate the benefits of introducing appropriate carbon prices earlier rather than later.

Each scenario combines assumptions related to (i) the introduction of a public policy measure (a higher carbon tax); (ii) productivity shocks resulting from the insufficient maturity of technological innovations (higher energy prices, including for low-carbon sources of energy that may not meet expectations); and (iii) the crowding-out effects on investment in non-energy sectors (lower productivity gains than expected in the orderly scenario). The simulations show that in both the United States and the European Union, real GDP would be lower by 2050 under a delayed transition scenario, where appropriate carbon prices were introduced late, than under an orderly transition where appropriate carbon prices were introduced immediately. A delayed transition also leads to higher inflationary pressure and a negative impact on public finances in the long term compared with an orderly transition. Moreover, a sectoral decomposition shows that the simulated effects on the sectors exposed to delayed transition policies are substantial and could give rise to financial stability risks that are potentially much more pronounced than suggested by aggregate results.

Other examples of scenario analysis can be found in NGFS (2021e) and ECB (2021). The latter in particular provides a number of simulations based on the assumption of a lower natural rate of interest, more frequent demand and supply shocks and the more limited ability of monetary and fiscal policies to provide macroeconomic stabilisation in the face of standard business cycle fluctuations. These simulations show that under plausible scenarios, climate change could restrict the ability of macroeconomic stabilisation policies to respond to standard business cycle fluctuations. Because the simulations are obtained from the European Central Bank's New Area Wide model, i.e. the model that ECB staff routinely use for the Bank's macroeconomic projections, the exercise is also an illustration of how it is possible to integrate climate change considerations in existing macro-econometric models.

A further example of scenario analysis is provided by McInerney (2022), illustrating the economic impact of different transition scenarios designed by the NGFS in Ireland. Being focused on the case of a small open economy, the simulations provide insights into the international impact of the various scenarios, highlighting the potentially large spillovers that may arise for a small open economy from transition policies in other countries.

3.3. Trade-offs

Among the actions that central banks can consider to better incorporate climate change considerations into their policy frameworks, more research on how climate change will affect the macroeconomy and refining the analytical tools used in support of their policy decisions is the least controversial. Nor does this action face major limitations, as it is broadly viewed as supporting central banks' price and financial stability mandates. It is therefore seen as fully coherent with narrower and more conventional interpretations of central banks' mandates.

However, there are some trade-offs when adding climate modules to central bank models, depending on whether a central bank envisages modelling climate change factors in much detail or plans to focus on the most important aspects for the country in question. These trade-offs can be exacerbated, depending on whether the existing model is a large-scale model that features all aspects of the economy that matter for central banks or a medium-sized model focusing on the most important ones.

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A large-scale model with a detailed climate module provides adequate coverage of the key economic and climate-related transmission mechanisms and variables required to support policymakers' discussions. However, theoretical soundness and comprehensiveness often come at the cost of tractability and flexibility. Compared with their large-size counterparts, medium-scale models are easier to use and understand, and are reliable and robust. They are also more flexible, making it possible to easily examine the implications of alternative economic and climate-related assumptions or parameter values.

There is no single model that works for all situations and all central banks. Rather, the features included in the model are likely to depend on country characteristics as well as on the type and severity of climate-related risks a country is already facing now.

4. Lessons learned to date

With the climate agenda becoming increasingly prominent for several central banks, efforts to develop more comprehensive modelling frameworks have been scaled up. Several central banks have announced plans to develop tools to better understand the macroeconomic effects of climate risks. For example, a comprehensive set of actions was announced by the ECB in July 2021 as part of its action plan on climate change, which followed the conclusion of its strategy review. The action plan contains a series of initiatives aimed at expanding the ECB's analytical capacity in macroeconomic modelling, statistics and monetary policy with regard to climate change.

In particular, in the near term, the ECB committed to improving its projection baseline by including assumptions on carbon pricing from the EU Emissions Trading System in its short-term forecasts and evaluating the impact of climate-related fiscal policies on its baseline projections. In the medium term, the ECB also committed to scaling up its macroeconomic modelling and scenario analyses, by: integrating climate risks into the ECB models and assessing impacts on potential growth; conducting scenario analyses on transition policies; and modelling the implications of climate change for the monetary policy transmission mechanism. Acknowledging the need for more comprehensive information on carbon emissions, climate exposures of banks, debtors and sectors, and on fiscal climate measures to complement its modelling effort, the ECB also announced various actions to improve the availability, consistency and reliability of climate data, to better identify and manage climate risks (see ECB, 2021).

Some institutions, such as the Bank of Canada, have adapted available climate-economy models that have been applied in other contexts for use in climate-related scenario analysis, in order to examine macroeconomic, sectoral and technological changes (e.g. the MIT Economic Projection and Policy Analysis model in Ens and Johnston, 2020). Some, such as De Nederlandsche Bank and the Banque de France, have translated climate scenarios designed with climate models into a set of macroeconomic effects by using standard multi-country macroeconometric models, such as the National Institute's Global Econometric Model (NiGEM) (see Vermeulen et al., 2018; Allen et al., 2020). Others, including the Reserve Bank of India, have applied time-series methods to assess the impact of climate change on inflation and economic activity (Reserve Bank of India, 2020).

A lesson learnt from the experience so far is that no single model can answer all questions but different models could complement each other and fit different purposes. For example, while traditional models are not designed to feature climate change, they can be used – in combination with climate-specific models using a suite-of-models approach – to study the implications for monetary policy of different climate scenarios, as done, for example, in ECB (2021). Scenario analysis could complement traditional models, particularly in dealing with uncertainty. Moreover, as noted in NGFS (2020a), interdisciplinary collaboration is essential to best reflect climate trends and risks in macroeconomic models. In dealing with issues that typically lie outside their natural remit, central banks could find it beneficial to share their research agenda more broadly, seeking relevant expertise in environmental economics, as discussed in Section 5 below.

Overall, as noted by NGFS (2021a), given the still preliminary stage of this strand of literature, there is ample room for further work to develop more adequate models for central banks to account for the impacts of climate change.

5. Recommendations: the way forward

A suite-of-climate-models approach is recommended as a way to integrate climate-related risks in central banks' forecasting frameworks. Forecasts and scenarios obtained from the workhorse models can be conditioned on outputs from climate

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models in the suite, thereby covering for the lack or limited representation of climate-related risks in the workhorse models. Over the long run, climate-related risks should be integrated into the workhorse models, while keeping the suite of models as a hedge against model uncertainty.

When developing climate models for the suite and climate-proofing their workhorse models, central banks should follow an interdisciplinary approach by collaborating with researchers from a wide range of academic disciplines. For example, central banks could rely on meteorologists for the weather forecasts and atmospheric data that they need to augment their short-term forecasting and nowcasting tools. They may also cooperate with climate scientists to develop realistic warming scenarios caused by alternative pathways of economic development. Engineers can provide valuable technical expertise to enable central bank economists to better understand the extent to which technological progress may reduce carbon emissions in certain sectors, helping to decouple economic growth from carbon emissions. They could also provide insight into the possibility of scaling up carbon capture technologies, which could enable more informed choices to be made around the damage function in IAM models and other relevant parameters of more structural models.

“Central banks should start considering the economic impact of other aspects of environmental degradation, such as the loss of biodiversity.“

Climate-proofing central bank models requires high-quality climate data. Central banks could promote the availability of better, more comprehensive climate-related data by supporting disclosure practices in financial markets with their operations. For example, central banks could subject the acceptability of certain securities and financial assets in their monetary policy operations, or the eligibility of certain counterparties, to specific disclosure requirements and information standards. This would nurture better market practices and standards and foster data dissemination. They could also advocate and support international initiatives to make such disclosures mandatory, and use their in-house rating system to assess climate risk, as suggested by Abdelli and Batsaikhan (2022). Central banks could support ongoing initiatives at the national and international level aimed at identifying taxonomies of sustainable and polluting activities. They could also support national statistical agencies to construct and make available indicators that central banks need to build their climate models.

Central banks should make use of scenario analysis to assess how climate-related risks affect the macroeconomy while at the same time acknowledging various dimensions of uncertainty associated with analysing climate change.

Finally, central banks should start considering the economic impact of other aspects of environmental degradation, such as the loss of biodiversity. While research in this area is still in its infancy, recent studies on the financial market impact of biodiversity loss suggest that this is a topic central banks should not ignore (Salin et al., 2021; NGFS, 2021d).

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