WORKING PAPER · NO. 2021-64

Central Banking Challenges Posed by Uncertain Climate Change and Natural Disasters

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SEPTEMBER 2021

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September 3, 2021

Abstract

Climate change poses an important policy challenge for governments around the world. The challenge is made all that much more difficult because of the multitude of potential policymakers involved in setting the policy worldwide. What then should be the role of central banks? How are climate change concerns similar to or distinct from those of other natural disasters? Clarity of ambition and execution will help to ensure that central banks maintain credibility. By adhering to their mandated roles, they retain their critically important distance from the political arena. Their credibility will be further enhanced by avoiding the temptation to exaggerate our understanding of climate change.

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*Prepared for the 2021 Carnegie-Rochester NYU Conference on Central Banking in 2020's and Beyond. In preparing this manuscript, I benefitted from reading and discussing a preliminary draft of a report on "The Resilience of the Financial System to Natural Disasters" at a March 18th and 19th, 2021 conference sponsored by the IESE Banking Initiative. I thank Mike Barnett, Mark Bills, Buz Brock, Darrell Duffie, Peter Hansen, John Heaton, Anil Kashyap, Narayana Kocherlakota, Andreas Lehnert, Lubos Pastor, Monika Piazzesi, Glen Rudebusch, Doug Skinner, Tony Smith, Grace Tsiang, Xavier Vives, and John Williams for helpful discussions and comments and Diana Petrova for feedback and assistance throughout the process of preparing this manuscript. Valentina Solano and Zhenhuan Xie provided further assistance in the final draft preparation.

1 Introduction

The potential hazards of climate change have become explicit policy concerns of government officials as well as the general public. Many now understand that long-lasting damages to the planet's capacity to sustain life will occur without action. Economists, since Pigou (1920) have long identified pollution as a negative externality in production and consumption. Individuals, businesses and institutions that engage in activities that increase greenhouse gas emissions are not taking into account the ill-effects of their actions on others, a concern that extends well beyond pollution and into other potential damages in the future that could be induced by climate change. Economists have further proposed directly addressing this market error by imposing a carbon tax, or capping production and creating a market in production licenses, thus making clean production an opportunity for those for whom it is cheapest, and making pollution an option only for those for whom clean alternatives are the most costly. More generally, effective climate policy levers are in the fiscal but not in the monetary toolkit. Even so, enacting taxes has politically challenging distributional consequences. While classroom exercises focus perhaps too much on deadweight loss triangles, in practice, the tax revenue rectangles are of higher value, and there are limited economic principles to guide how those are distributed to best aid policy aims. Nevertheless, from an overall viewpoint, the most impactful place for climate change policy would seem to be in the fiscal realm of tax legislators and coordinated responses across governments and regions around the world and not from the monetary policy arena.

Why look to central bank policy as a featured way to combat climate change? We have seen political wrangling prevent the creation of coherent tax policy or cap-and-trade policy within countries as well as between countries. Does distance from the political arena make central banks more attractive resources for shaping policy on climate? Does the vital importance of climate change for society justify working on it from all possible policy angles at the same time? While some are embracing this as an attractive route, I see three potential dangers:

i) hastily devised policy rules unsupported by empirically grounded quantitative modeling could backfire if or when climate policy targets are missed, harming reputations of central banks and weakening their ability to act in the future on a variety of fronts;

ii) attempts to take on a broader mission without formal and well-defined mandates could compromise central bank independence in the longer run;

iii) climate change mitigation targets added to currently well-defined mandates may generate excessive expectations and unwarranted confidence in the abilities of central banks to address this important social and economic problem while diverting the attention away from fiscal policy.

The remainder of this paper is devoted to exploring these potential policy pitfalls. My discussion will be organized around the following five topics:

- Modeling systemic risk and climate change in support of rules-based policy for financial stability
- Quantifying the exposure of financial institutions and businesses that receive their loans to uncertain climate change outcomes
- Stress testing banks based on long-term possibilities of climate change
- Slanting central bank portfolios towards green technologies
- Comparing climate change challenges of central banks to those connected with other natural disasters

2 Models and mandates

> I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the state of science, whatever the matter may be. Lord Kelvin, 1883.

While Lord Kelvin was a mathematical physicist, this charge has also been directed to the social sciences. See, Merton et al. (1984). We could have an interesting discussion about the merits of this dictum, as some find it controversial or naive. To their credit, central banks have used quantitative modeling to support policy-making directed at their mandates. While many have emphasized advantages to rules-based policy making, the merit in such rules gain credibility by quantitative modeling backed up by empirical evidence. Part of the desired transparency and credibility of a policy rule is provided by transparency and credibility in the modeling and evidential support of that rule. Quantitative modeling aids our understanding of how policies address central bank mandates. This enhanced understanding helps to keep some valued distance between policy and politics. Moreover, the construction and use of models open the door to constructive criticism from outside researchers. In their recent report on productive ways to support a transition to a net-zero economy, the The Group of Thirty (G30) Steering Committee and Working Group on Climate Change and Finance (2020) used well-defined policy mandates for central banks in regards to employment and inflation as a good example of how to establish credibility of long-term targets. Relatedly, in a prior discussion of financial stability, Kocherlakota

(2015) also looks to central banking experience with inflation and employment for examples of well-formulated long-run quantitative targets.

Credible models provide support for credible policies. What, then, do we mean by "credible models?" I think of the productive use of highly stylized models as a form of "quantitative storytelling." The models we use, as is easily seen in the study of economic dynamics, are not meant to be fully comprehensive. As noted in the well-known quote from George Box:

> Now it would be very remarkable if any system existing in the real world could be exactly represented by any simple model. However, cunningly chosen parsimonious models often do provide remarkably useful approximations. Box (1979)

This "substantive models are expected to be misspecified" perspective extends more generally across scientific applications, although the quality of the approximation varies extensively across disciplines and applications. Nevertheless, we build and use models because they provide guidance that a) helps our understanding of how policy works and b) allows for predictive statements about policy outcomes. While there is very little insight to the observation that models are misspecified, there are reasons to conjecture how the potential misspecification could unravel the insights or overturn the predictions in quantitatively important ways. Entertaining multiple models with differing implications for predictions adds an additional consideration, but acknowledging this multiplicity does not undermine their use. Indeed, the idea of quantitative storytelling with "multiple stories" will capture many policy challenges with dynamic implications.

The need to explore alternative models and the potential misspecification of each is indicative of the limitations of our current body of knowledge. As we aim to use models as credible guides to policy over longer horizons, it is also important that we leave the door open to advances in our understanding and the corresponding "updating" of the policy rules. While this is a central feature of decision theory under uncertainty in dynamic environments, it could appear to challenge the credibility of policy and its transparency. Economic policies necessarily confront tradeoffs, and the understanding of those tradeoffs could change with new information and experience. This is, no doubt, an important consideration in designing policies to confront climate change. Decision theory does not lead directly to the conclusion to do nothing until we learn more. But the need for adaptation to future knowledge advances can also be mistaken for discretion, seemingly undermining policy credibility. With these limits to our knowledge, communication of policy aims and means for attaining those aims becomes more challenging to ensure credibility. While true, this is hardly an argument against confronting uncertainty openly.

How does central bank policy in regards to climate change fit into this discussion?

3 Systemic risk and climate change

Since climate change or natural disasters could induce instability in the banking sector, then perhaps we should just add some big shocks to our models of financial stability. In a later section, I discuss the distinct modeling and measurement difficulties related to exposures to climate change uncertainty. More generally, we are still in the early stages of building quantitative models of so-called "systemic risk" in the financial system, where systemic risk is envisioned as a rationale for creating a need for central banking policy intervention that extends beyond the microprudential regulation of individual banks. Similarly, as I will discuss later in this section, we are in the early stages of building quantitative models of the two-sided feedback between climate change and economic opportunity.

3.1 Mandates

From a policy perspective, central banks approach this challenge differently. While the Bank of England has a distinct Financial Policy Committee, in a recent report, the Board of Governors views financial stability within their existing dual mandate as expressed at the outset of a recent report:

> Promoting financial stability is a key element in meeting the Federal Reserve's dual mandate for monetary policy regarding full employment and stable prices. In an unstable financial system, adverse events are more likely to result in severe financial stress and disrupt the flow of credit, leading to high unemployment and great financial hardship. Board of Governors of the Federal Reserve (2020).

Kashyap and Siegert (2020) argue that the current mandate only gives the Federal Reserve a limited role to address financial stability, while acknowledging interactions like those noted in this quote. The financial stability mandates for developing countries vary as does their political independence. For instance, see Dikau and Volz (2021) for a cross-country comparison of mandates.[1]

3.2 Models

To construct a rules-based approach to systemic risk policy introduces a modeling challenge that I originally wrote about a decade ago. See Hansen (2014). Kocherlakota (2015)'s discussion, which I mentioned previously, of what is required for central bank mandates to be effective, expressed skepticism of financial stability as a third mandate. Tucker (2019) argues that financial stability is different from other central bank mandates because many potential policy levers require opaque

[1] They include a discussion of the differential promotions of green finance across the various central banks.

execution; but my discussion in this section explores an alternative challenge from his. Better models of financial stability would help to remove the opacity of design and ambition of central bank policy in this arena.

The financial crisis exposed limitations in existing models that were used previously to guide central bank policy. Since writing Hansen (2014), the economics and finance professions have produced research that has advanced our understanding of financial crises like the global crisis that we recently experienced. It remains to be seen if the initial modeling repairs that emerged will indeed blossom into good guides for future policy directed to financial stability, or if lower-dimensional models with more fundamental nonlinearities that have emerged are better suited to provide policy guidance. Overall progress, in my view, currently falls short of providing a model or even a small set of models that are broadly embraced for quantitative predictions.[2] Even if my assessment of existing quantitative models of "systemic risk" is unduly negative, these models were not built with climate change concerns in mind. Thus, it remains to incorporate climate change into this modeling of financial stability. It seems quite a jump to go from existing central banking successes to articulating a counterpart role for central banks as they confront climate change.

3.3 Climate economics modeling

A suite of integrated assessment models in climate economics seek to guide prudent policy making and an emerging body of empirical work aim to provide a better understanding of the potential damages that could be induced by climate change. This literature is motivated by a particular (non-pecuniary) externality: carbon emissions today damage the environment and economic opportunities in the future. These damages are not fully internalized by market prices. Potentially, climate change brings together the conflagration of two policy challenges: financial stability and the external impact of carbon emissions.

Understanding the current state of climate-economics modeling, including the uncertainties and shortcomings that exist, is vital for understanding the likely effectiveness of central bank policies related to climate change. This leads me to explore the climate change literature to see what lessons might be pertinent for building models designed to support central bank policy-making. While there is a substantial body of evidence supporting the adverse human imprint on the environment, uncertainty and knowledge limitations come into play when we build quantitative models aimed at capturing the dynamic transmission of human activity on the climate and adaptation of economic activity to climate change. This uncertainty needn't undermine modeling efforts but should shape how models are used to impact policy.

[2]Interestingly, Lord Kelvin was over-confident in one of his own attempts at quantification when he erroneously argued that Darwin's theory was flawed because it required a much larger age of the universe than was supported by his calculations. Lord Kelvin failed, however, to consider radioactivity in his computation of the age of the Sun.

A focal point of much of the climate-economics literature has been the social cost of carbon (SCC). I describe two different SCC constructs that have been used in this literature. Both are marginal calculations based on presumed climate change externalities. Both are intended as social values of emissions relative to some aggregate consumption numeraire. Finally, both have interpretations as asset prices for adverse social payout processes over future time periods induced by current marginal change in emissions. They differ in terms of the baselines used for the local perturbations.

One notion of the SCC can be tied directly to a Pigouvian tax on carbon emissions necessary to support a social optimum. See, for instance, Golosov et al. (2014), Nordhaus (2017), Cai et al. (2017), and Barnett et al. (2021). In this approach, the SCC is the social shadow price of emissions computed at the socially efficient allocation. Recursive, dynamic programming type methods are typically used in such computations, and recursive characterizations of uncertainty are often included in the computations. While the SCC is a relative price, the baseline (often stochastic) allocation used to deduce this price comes from solving a global policy problem.

A second notion of the SCC is typically static in nature and is not directly tied to Pigouvian tax policy. It relies on scenarios that provide exogenous paths for emissions or atmospheric carbon and simulation methods to compute the marginal implications for economic damages of changing emissions. See National Academies of Sciences, Engineering, and Medicine (2017) and NYSERDA and Resources for the Future (2021) for a discussion of these methods. Uncertainty quantification for this second notion relies on probability assignments to the alternative scenarios, but without a dynamic recursive structure. The National Academies of Sciences, Engineering, and Medicine (2017) emphasize a modular feature of the computations with four components: socioeconomic, climate, damage and discounting with potentially distinct expertise contributing to each of the components. As Barnett et al. (2021) argue, coherent dynamic approaches to the inclusion of uncertainty in such computations lead naturally to a more integrated approach because there are important interactions across these four components. Taking these interactions into account makes modeling efforts all the more challenging.

I give two examples of the interactions among components that come to the forefront with more ambitious approaches to uncertainty. First, as many argue, there is uncertainty about the damages that will be induced by climate change. We expect such damage uncertainty to be at least partially resolved as the environment degradation is revealed in the future. So called "business-as-usual" trajectories, or, more generally, high carbon emission trajectories are likely to induce some type of policy response if damages turn out to be more severe than initially anticipated. On the other hand, we might expect a much more muted policy response if damages turn out to be surprisingly modest. In other words, the plausibility of the scenario would seem connected to damages that the scenario might induce in the future. At the very least, we would expect some probabilistic dependence across scenarios and potential damages that will be partially resolved in the future. Later, I will have more to say about the use of analogous scenarios for central bank policy making.

As a second example, consider the "discounting module." From standard asset pricing calculations, we know the importance of "stochastic discounting" whereby, in effect, discounting depends on how the cash flow being valued is exposed to uncertainty. Even after broadening our conceptualization of uncertainty, such stochastic or probabilistic representations of valuations remain valid with the appropriate adjustments to the probabilities. This observation about market valuation carries over as well to social valuation as Barnett et al. (2020) show. Discussions in environmental economics about how to discount the future are framed too narrowly for valuation under uncertainty pertinent to climate change and other realms of policy making. The important point is that the valuation adjustment for uncertainty that takes the place of simple discounting depends on uncertainties from the other modules.

To illustrate uncertainties, consider the "climate module." There exist many large scale geoscientific models designed to address climate change as implied by exogenous emissions or atmospheric CO_2 paths that have dynamic richness as well as spatial heterogeneity. For an integrated approach, it is not tractable to plug these climate models into an economic model with forward-looking economic agents or policymakers. One revealing way to make model comparisons is to run common pulse experiments across the set of alternative climate models. In Figure 1, I report the outcome of such experiments as tabulated by Barnett et al. (2021) and based on work by Joos et al. (2013), Geoffroy et al. (2013) and others.

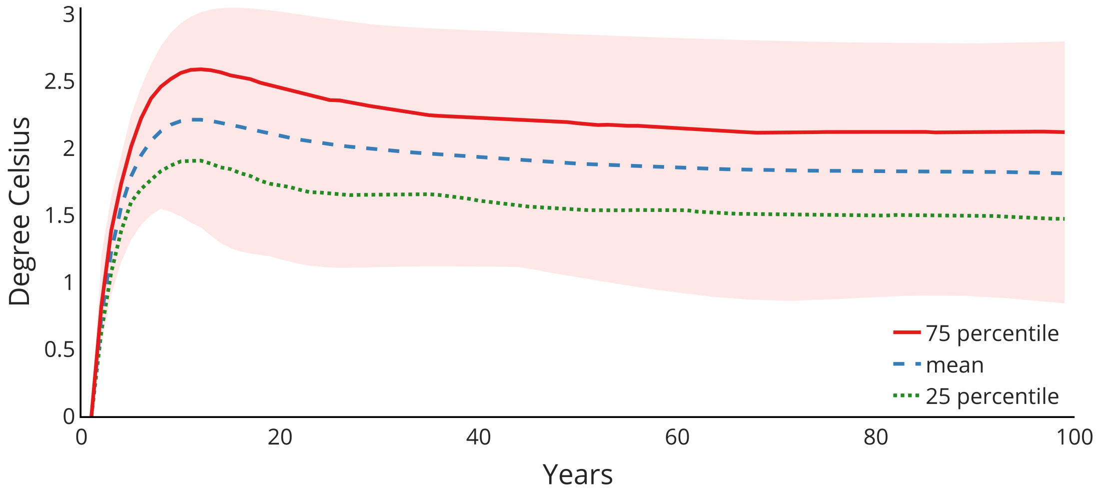


Figure 1: Percentiles for temperature responses to emission impulses. The emission pulse was 100 gigatons of carbon (GtC) spread over the first year. The temperature units for the vertical axis have been multiplied by ten to convert to degrees Celsius per teraton of carbon (TtC). The boundaries of the shaded regions are the upper and lower envelopes. These responses are convolutions of responses from sixteen models and temperature dynamics and nine models of carbon concentration dynamics giving rise to 144 model combinations.

Figure 1 captures the resulting temperature responses across various sets of the 144 models resulting from calculations. The maximal temperature response to an emission pulse occurs at about a decade and the subsequent response is very flat, matching the response patterns featured by Ricke and Caldeira (2014). For a further characterization of this heterogeneity, we compute the exponentially weighted average of each of these response functions and use them in our computations. We report the resulting histogram in Figure 2.

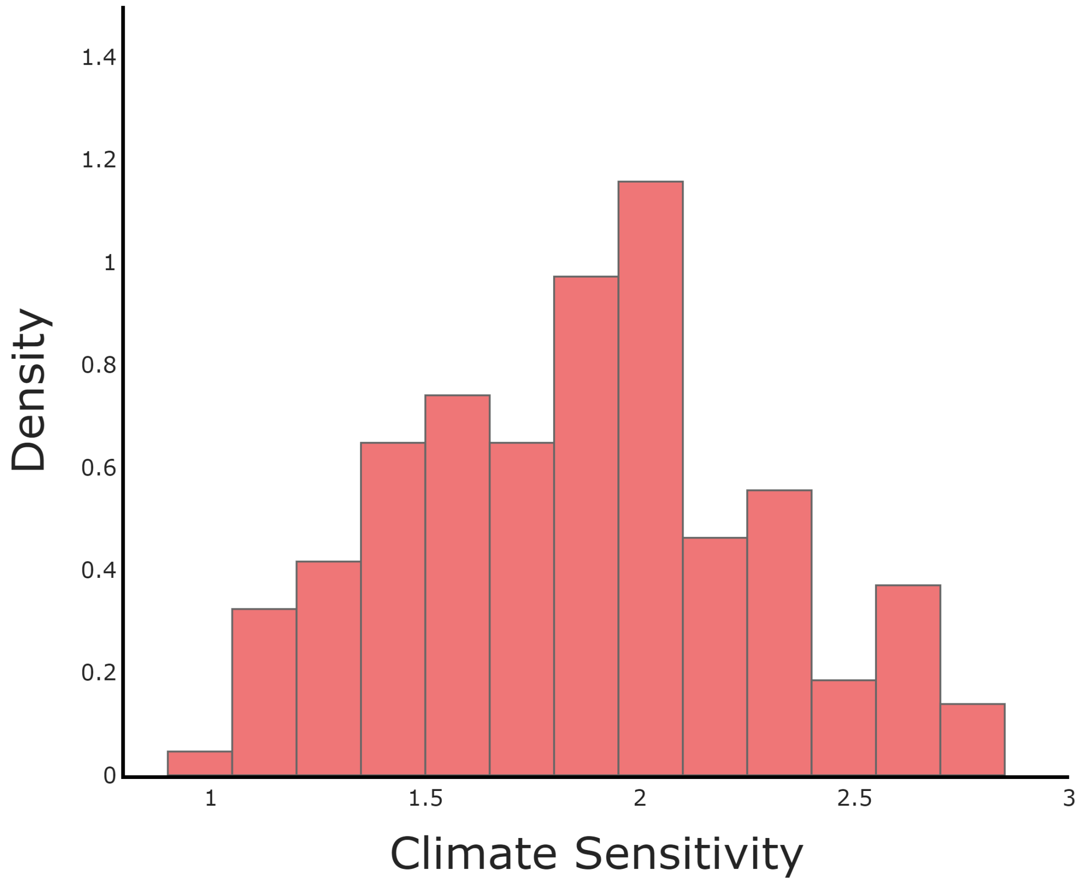


Figure 2: Histograms for the exponentially weighted average responses of temperature to an emissions impulse from 144 different models using a discount rate of one percent.

This histogram displays the substantial amount of cross-model uncertainty that could emerge from a climate model. This relatively simple, linear representation of dynamics is sometimes used as an "approximation" in economic analyses. Thus this very linear characterization of the climate dynamics gives a convenient representation of the cross-model heterogeneity in how the emissions today alter temperature in the future. It masks, however, some potentially important nonlinearities including potential tipping points that might occur.[3]

In building integrated assessment models, economists add simple depictions of damage functions, often static, that are intended to capture productivity losses induced by climate change. This is part of the "damage module." Uncertainty comes into play because of our limited knowledge of how economies will adapt to climate change and how this will play out over time. It

[3]As another form of potential nonlinearity, pulse sizes can matter for how emissions influence carbon concentration beyond a simple linear scaling. Depending in part on the size of the pulse, this linearity is at least partially offset by what is called the Arrhenius equation.

is damage function uncertainty that is the "Achilles' heel" of integrated assessment models of climate change. Carleton and Greenstone (2021) provide a revealing and extensive discussion of damages and what is missing from simple damage function specifications. They look to empirical approaches and new sources of evidence as the path forward. While comprehensive and thoughtful empiricism will be revealing, modeling challenges cannot be avoided as we push developing and advanced economies into realms for which we have virtually no historical experience.

The stark simplifications and the associated uncertain model approximations, including in particular damage functions have led some to challenge the use of so-called integrated assessment models. For instance, Pindyck (2013) and Morgan et al. (2017) find existing integrated assessment models in climate economics to be of little value in the prudent conduct of current policy. Morgan et al. note the value of such model building for enhancing our understanding of an important social problem, a conclusion that I also see as having considerable merit.

To summarize, while there are many qualitative models that speak to systemic risk, credible quantitative modeling is still in its very early stages. In my view, the same observation applies to climate-economic models. As I have argued, some progress has been made in assessing the uncertainties related to climate change, but the quantitative climate/economic models to date have not been designed with financial stability as their primary aim. Including climate change in the list of important modeling challenges aimed at enhancing our understanding of financial stabilty leaves quite a bit of guess work left for prudent decision-making. Encouraging central banks to fly blindly into a new realm could also prove harmful to central bank reputations. Proceeding with a pretense of knowledge might support an activist central bank approach to climate change in the short run but might damage central bank reputations over the longer run. Any excessive confidence in our understanding could backfire over the longer haul and hinder credibility through false promises of success. For these reasons, I am skeptical that in the near term quantitative modeling can provide the meaningful support for rules-based systemic risk policies that incorporate the climate change concerns.

An investment in building better quantitative models that explore how climate change might challenge financial stability is a worthy venture. One could argue that bad numbers are better than no numbers, but I prefer an appeal to modern decision theory under uncertainty to address model ambiguity or misspecification concerns. I see virtue in the use of decision theory as a language for how to frame decision-making in an uncertain environment, even if it is used only at an informal level. Application of decision theory, however, will not eliminate knowledge gaps that we are looking to fill when speculating about potential externalities that climate change uncertainty might impose on the financial system. Rather, it will provide a coherent way to acknowledge these gaps and pinpointing where these gaps matter. In so doing, we will also expose some of the most productive directions for future research.

4 Quantifying Exposures to Climate Uncertainty

In addition to arresting systemic risk, another role for financial regulation is to monitor exposure of financial institutions to "big shocks" to the economy. If regulated firms are poorly prepared for pervasive turbulence, then this could hinder the provision of financing for productive ventures. I find it useful to distinguish the notion of systemic risk, meant to be a central rationale for macro-prudential policymaking, from "systematic risk," which is featured in models of asset pricing. In the standard asset pricing setting, systematic risk is present because of the investment exposure to aggregate shocks. Since such shocks cannot be diversified away in the cross section, their exposure requires compensation in financial markets. Market prices for the exposures to systematic risk are determined endogenously as part of market equilibrium and can be modeled as such or can be represented flexibly. The presence of systematic risk is not evidence, in and of itself, of a financial market failure nor should we look to policies to offset all forms of systematic risk. The connection to policy depends on the source of the systematic risk.[4] Why might climate change or other natural disaster shocks require the special attention of central banks in their regulatory role? The standard toolkit of financial engineering may be poorly adapted for quantifying such exposures, leaving the entire financial sector ill-prepared. While this may be true, central banks are not currently well positioned to address this shortfall by being external monitors. I will argue that going forward, progress can be made by first broadening how we conceptualize this uncertainty and then exploring the resulting measurement challenges.

In the case of climate change, we might worry about quantifying the exposures to potentially big climate shocks. But over what time horizon do we expect this shock to play out and with what advanced warning signals? There are repeated references in the literature to *physical risks* and *transition risks* related to climate change.[5] Physical risks include the varied consequences of weather-related consequences or other potentially environmental implications of climate change. One possible source of physical risks are so-called tipping points that have been discussed in the geoscientific literature. See for instance, Lenton et al. (2008) for a discussion of sources of tipping points and Cai et al. (2015) for a discussion of their implications for cost benefit analyses. But while this uncertainty may unfold essentially instantaneously at geo-scientific time scales, that notion is very different from the high-frequency perspective we often see in financial engineering. While "tail risk" might seem like a correct statistical analogy, the potential nonlinear unfolding of degradation of the environment induced by climate change seems more like a "large deviation" type assessment with a compounding or mushrooming of bad outcomes over a short time horizon

[4]Tucker (2019) correctly notes that microprudential regulation is not really distinct from its macroeconomic counterpart as the collective response of the banking sector to a macroeconomic shock may still be under the watchful eyes of regulators.

[5]See, for instance, the Bank of England discussion: https://www.bankofengland.co.uk/knowledgebank/climate-change-what-are-the-risks-to-financial-stability. They include a third category they call "liability risk." I quote: "if future generations do suffer from climate change, who will they hold responsible?"

rather than a single tail event. Another possible source of physical risk not often referred to in central banking discussions is the geoscientific model uncertainty that I displayed in the first two figures. This type of model uncertainty is likely to be resolved slowly as researchers continue to sift through the implications of various models of climate change.

Transition risks are associated with uncertainty associated with how policy and technological innovation will respond to climate change as it unfolds in the future. As economies push towards carbon neutrality, some sectors will be more dramatically affected than others, but uncertainty in the development of new technologies will spill over to uncertainty in the transitional responses. More generally, we are unsure how economies will adapt to future climate change. Economists often use the grab bag of a damage function as a simplified way to capture the economic consequences of climate change. Thus damage function uncertainty is an example of "transition risk." As a source of uncertainty, it is substantial now because of the lack of evidence of how the global economy will respond to climate change. As we inflict more serious damages on the environment, learning about damages could well occur much more rapidly, an implication that is featured in Barnett et al. (2021). Policy uncertainty is another form of transition risk.[6] Currently, enterprises are left to speculate about when more severe constraints or regulations might be imposed in the future and what their form will be.[7] A primary example of this is the well known stranded asset problem whereby a surprise change in future policy could make carbon-based assets lose their value.[8] While central banks seeking policy transparency may avoid adding to policy uncertainty, the regulated financial institutions themselves provide finance for businesses that are left to speculate about unknown policy interventions coming from outside the realm of central banking. Notice that the distinction between physical risks and transitional risks becomes blurred because transition risks can be induced by physical risks.

It would seem, at least in the shorter run, that uncertainty in policy responses to climate change and other shorter term vulnerabilities are likely to command the most attention of businesses and financial institutions. Engle et al. (2020) assembled and used textual evidence to form portfolios designed to hedge climate change risk. Their analysis is being extended to provide evidence about the quantitative magnitude of the climate uncertainty components. Textual analysis from newspapers, while revealing, may give a distorted perspective with little press attention to risks that unfold over longer horizons, but this may not be an important bias when forming hedge portfolios or assessing the impact of climate change in the near even if this approach downweights uncertainty that plays out slowly or only emerges well into the future. As an alternative approach, Kling et al. (2021) have used the ND-GAIN (Notre Dame Global Adaptation Initiative) climate

[6]In direct correspondence, Darrell Duffie has perceptively pointed to sovereign default triggered by climate change as a potentially dramatic form of transition risk that might face developing countries in the future.

[7]See Krueger et al. (2020) for survey evidence about this concern.

[8]See Barnett (2019) for a model and analysis of valuation implications of stranded assets induced by policy uncertainty.

vulnerability index to measure exposure to climate change.[9]

In terms of assessing exposure to "physical risk" or even "transition risk," what are we expecting from large scale financial institutions? How do we expect regulators to assess their exposure as climate change unfolds over decades or at least multiple years and not days? Transparency in policy requires clear answers to these questions.

It is good to proceed with oversight plans with eyes open. It is naive to expect research departments of either central banks or financial institutions to have an easy time with climate change risk assessment. It makes good sense for many firms, financial and non-financial, to assess their longer term vulnerability to climate change. Thus, they should at least have incentives to do this on their own. Given that we have much to learn, it will be a challenge for a regulator to monitor the credibility of climate risk management. Both the regulators and the regulated are exploring new territory in terms of uncertainty quantification.

When thinking about uncertainty and models, I find formal notions of risk to be too narrow of a construct. This is particularly true for climate change. Instead of risk, I find the following categorization to be revealing from the standpoint of uncertainty quantification:[10]

i) risk - unknown outcomes with known probabilities

ii) ambiguity - unknown weights to assign to alternative probability models

iii) misspecification - unknown ways in which a model might give flawed probabilistic predictions

Risk and risk aversion are typically presented and studied in economics classes. The rational expectations hypothesis adds even more constraints on how decision makers confront uncertainty. Specifically, dynamic, stochastic equilibrium models often assume that economic agents and policymakers, say in Ramsey-type problems, know the model consistent probabilities. In many settings, this may well be a very good approximation, but when evidence is sparse, the application of rational expectations becomes less compelling. Confronting ambiguity over models is what the statistics and econometrics disciplines have wrestled with for decades. Here, I think of a model as inclusive of the parameter values, and I do not draw a distinction between unknown parameters and unknown models.[11] The elegant Bayesian approach imposes a subjective prior that gives an initial weighting over alternative models and updates these probabilities as evidence unfolds via Bayes' rule. A robust Bayesian explores prior sensitivity, which can be important when the evidence is weak along some dimensions.

A "let-the-data-speak" mentality is sometimes embraced by looking to "uninformative priors." The rationale for using such priors is to minimize the impact of subjective prior distributions. In

[9]The aim of the ND-GAIN measure is a bit different. It is a country-wide measure is meant to help prepare both the private and public sector for climate change.

[10]See, for instance Hansen and Marinacci (2016).

[11]In other words, each parameter configuration indexes an alternative model.

the simplest of learning situations, data dominate priors making prior sensitivity less of an issue. But for challenges such as climate change, there is much we do not know about the geoscientific dynamics. If anything, understanding of the possible damages to the economy induced by climate change is even more sparse. At least along some dimensions, we seem quite far from a situation where data dominate priors. Moreover, the model construction itself needed to render the subjective probabilities meaningful requires subjective judgements, and different models can have substantially different implications for policy. Finally, the models themselves are abstractions or simplifications and by their very nature are misspecified. This opens the door to speculating how things might go wrong when using a model to guide policy, including in prudent business practice. This form of uncertainty may be the hardest one to address. If we knew what was wrong with a model, and we knew that this failing might have important consequences, then we would fix the model. Misspecification concerns emerge because we are unsure as to how to provide such a repair.

Decision theory has explored similarities and differences between risk and ambiguity as defined by i) and ii). Most prominent is the often used expected utility rationalized by theory of subjective probability combined with the independence axiom. See, in particular, Savage (1954)'s elegant axiomatic justification. Alternative approaches include dynamic versions of the smooth ambiguity model put forward by Klibanoff et al. (2009) and the recursive multiple priors model of Epstein and Schneider (2003) as a dynamic extension of the max-min utility model of Gilboa and Schmeidler (1989). Consider, for instance, the model heterogeneity revealed by Figure 2. This histogram is constructed by treating all models equally. The baseline probabilities are the same. Alternative climate science experts might assign other than equal weights. Prior sensitivity includes an investigation of how important this cross model weighting is for the decision problem under consideration.

Statisticians, econometricians and control theorists have explored different aspects of model misspecification, but formally incorporating the category iii) misspecification uncertainty into decision theory has received less attention. There is some work along these lines by Hansen and Sargent (2007), Hansen and Sargent (2020), and Cerreia-Vioglio et al. (2021). In practice, this is arguably the hardest of the components to address. If we knew how a model was misspecified, we would presumably fix it. Instead the aim is to accommodate model deviations posed in flexible ways. But for this type of exercise to have a meaningful outcome, there has to be some bound or penalization restricting the potential forms and magnitudes of the misspecification. Ignoring misspecification leaves model users guilty of taking their pre-specified set of models too literally.

Approaches along these lines give guidance for how to conduct sensitivity analysis when there is model uncertainty of the nature that seems pertinent for climate change. In effect, this theory provides low-dimensional characterization tradeoffs between a full commitment to baseline probabilities and probabilities that result from changing subjective inputs in ways that have adverse consequences for decision makers. The approaches build on the conceptual and computational successes of recursive, dynamic programming type methods. Part of any meaningful uncertainty quantification is a form of sensitivity analysis. The formulation of decision problems sharpens the focus of uncertainty quantification by integrating into the analysis the answer to the question, "sensitivity to what?" I argue that these uncertainty tradeoffs are revealing not only to policy makers but also to "risk management" efforts by private sector firms. They should be pertinent to both the entities being regulated as well as to the regulators themselves.

In a recent statement that has some notable similarity to the one that I quoted from Lord Kelvin, Governor Andrew Bailey of the Bank of England wrote:

> What we cannot measure we cannot manage, so it is important that financial firms and their clients use the TCFD framework and the latest tools available to measure, model and disclose the climate risks and opportunities they are exposed to today and in different future climate scenarios.[12]

There is a lot to unpack in this quote. The first is the reference to the TCFD (Task Force on Climate-related Financial Disclosures) framework. While disclosure of information could be revealing to potential investors and to regulators, TCFD framework was remarkably vague in terms of how to synthesize information, certify its quality or put this information to good use. As I have argued, the measurement/modeling challenges are nontrivial because we are potentially pushing economies beyond the realm of modern experience. We need more than the familiar tools of risk analysis. Finally, who will do the modeling and why should we have confidence in the modeling outcomes?

As I mentioned previously, private sector firms, including financial institutions, have incentives to do their own uncertainty management. Given this, why not offload most of the modeling efforts to the private sector firms and have the regulators trust their outcomes without getting lost in the actual details of the model constructions and subjective inputs? If indeed the regulator and regulated incentives were aligned, this could reduce the monitoring to that of a second set of eyes to achieve a common objective. But there are good reasons that the incentives are not fully aligned as part of the rationale for regulation. The European Central Bank has previous experience with using risk models of the regulated. Behn et al. (2021) documented systemic understatement of risk exposures when regulatory assessments rely on the modeling output of the large financial institutions. Indeed, sensitivity to subjective inputs gives model builders wiggle room in their risk assessments suggesting the importance of broadening how regulators conceive of uncertainty when assessing the exposures of the regulated. Without identifying the flexibility in the model specifications used by private sector banks, the door is wide open for slanting model predictions about implications of climate uncertainty.

[12] This is taken from a speech, Bailey (2020).

Given both past experience with model-based regulation and the uncertainties associated with climate change, a productive strategy going forward would be for central banking research departments, private banks risk assessment teams, and academics actively engaged in related research to collaborate in how to best measure the exposure of climate change to uncertainty, and its consequences. This research could include exploring alternative models related both to the physical and the transitional components to climate change uncertainty. These efforts would be well-directed to go beyond the realm of standard risk management methods to investigate formally sensitivity to modeling assumptions needed for designing prudent courses of action and for helping to fill in knowledge gaps. Such efforts would be most effective by exposing the impact of the subjective modeling inputs rather than disguising them and assessing their consequences. While I view this as no easy task, such an investment would seem to be vital to a central bank climate agenda in assessing vulnerability of the financial system to climate change.

On the other hand, there has been much value to the intellectual interactions between internal and external researchers that study closely related problems. There is reason for optimism because many central banks have already been investing in climate expertise and research departments at central banks have been constructive contributors to research in other areas pertinent to central bank policy. The NGFS (Network for Greening the Financial System) shows the willingness of central banks to coordinate best practices of their approaches to climate change. But there are also limits to in-house approaches to research. In-house research within central banking on their own without external collaboration are often of limited value, as internal researchers sometimes face short response times and are eager to adapt to the announced priorities of central bank leaders. An investment in an open and cooperative approach that embraces a broader notion of uncertainty beyond risk considerations and strongly encourages the active participation of external researchers with central bank encouragement seems a promising approach in the future. To be successful, this approach will need to recognize and appreciate the challenges and not oversell the current set of research tools available to address climate change and its uncertainties. The highly visible IPCC (Intergovernment Panel on Climate Change) successes were tied to its aims at information and insight sharing across researcher communities and disciplines, whereas what is needed is the encouragement to critically evaluate current approaches and nurture the development of new methods to meet the modeling and measurement challenges posed by climate change uncertainty as it unfolds in the near term and compounds over decades.

5 Scenarios and Stress testing

Tucker (2019) argued that an important virtue of stress testing is its transparency in the central banks' role of monitoring financial firms under their purview. There has been much interest among central banks for extending and applying the stress test methods to incorporate climate change. This has led to the design and use of scenarios for up to thirty years as the featured components to the stress tests. The substantially longer time frame changes dramatically the nature of such stress tests relative to other tests that have been executed since the advent of the global financial crisis. In addition to the relatively long time horizon, there are other features that are noteworthy given such an extended horizon. Each scenario is specified as a time path for a set of macroeconomic and financial variables without formal reference to likelihoods of each of the paths. This lack of a probabilistic perspective is remarkable given that scenarios are motivated as a way to support risk analysis. Moreover, there is no notion of uncertainty being partially resolved as the economy experiences future events. Quite simply, they cannot be used in conjunction with dynamic programming methods and Markovian representations of uncertainty, which are commonly viewed as tractable approaches to confronting uncertainty in dynamic environments. The dynamic decision theory referred to in section 4 is designed to confront uncertainty more broadly than the arguably narrow confines of risk analysis, but typically supposes that there are at least bounds on probabilities to give reasonable normative prescriptions.

While the proposed stress testing methodology is in many ways transparent, what we will really learn from such stress tests is not so transparent, as I will discuss. If the sole purpose is to encourage financial institutions to pay more attention to the longer-term consequences of climate change in their planning for the future, then this form of stress analysis could be a valuable approach. But many of the existing defenses for its use indicate that central banks have greater ambitions in mind which might well impose extra burdens on the financial institutions that are under their watch. In the remainder of this section, I consider what I see as pitfalls in this method in ways that leave the door open to better approaches.

The lack of a probabilistic perspective is seen by many as a virtue given our current understanding of climate change and its impacts. In their book cleverly entitled, "Green Swan," Bolton et al. (2020) called for new paradigms to confront the extreme uncertainty related to climate change and see stress tests based on long-horizon scenarios as central to the answer. In regards to stress testing based on scenarios, they write:

> Unlike probabilistic approaches to financial risk management, they seek to set up plausible hypotheses for the future. This can help financial institutions integrate climate-related risks into their strategic and operational procedures (*e.g.* for the purpose of asset allocation, credit rating or insurance underwriting) and financial supervisors assess the vulnerability of specific institutions or the financial system as a whole.

This view of long-horizon scenarios is common in writings about central bank climate change prudential policy. For instance, researchers at the Dutch Central Bank seek to use stress testing to confront climate-related tail events without being distracted by probabilities:

> The first important aspect of the framework is that choosing a stress test approach

> leads to a focus on tail events rather than on a central path projection. The reason is the large degree of uncertainty surrounding climate change and the energy transition. One may argue that the uncertainty is fundamental, in the sense that probabilities of various transition paths cannot even be known (Vermeulen et al. (2019)).

It is noteworthy that the quote from Bolton et al. (2020) contrasts the forward-looking scenarios with probabilistic approaches and yet makes reference to "climate-related risks." This use of the term "risk" must differ from that given by i) in the decision theory categorization described in Section 4. While there may be a reluctance to assign probabilities, distinctions like "central paths" versus "tail events" make clear that some notion of likely and unusual outcomes is pertinent to the use of scenarios in sensible ways, both for financial stability analysis and for other purposes. This is all the more evident in the informative discussion, Allen et al. (2020), coming from the Banc de France and to some extent in the NGFS (2020) report on the potential use of scenarios by central banks. None of these studies, however, describe and justify a formal way for financial institutions to integrate pathways from such scenarios into their own decision making.

As discussed in Section 3.3, scenarios are used extensively in the climate economics literature, for example, to measure the SCC. Probabilities over scenarios are sometimes included to account for uncertainty in emissions and atmospheric carbon trajectories. But as I discussed, the plausibility of any given emissions scenario can change substantially in the future as more information about damages becomes revealed. More severe damages are likely to trigger a stronger policy response. This underscores the need for a more dynamic approach for even conceptualizing what scenarios should be considered and whether to classify them as plausible or worthy of consideration and unlikely but nevertheless interesting as possible bad outcomes.

In a comprehensive statement of planned policy, the Bank of England (2019) gave the following example of some pathways for thirty-year scenarios:

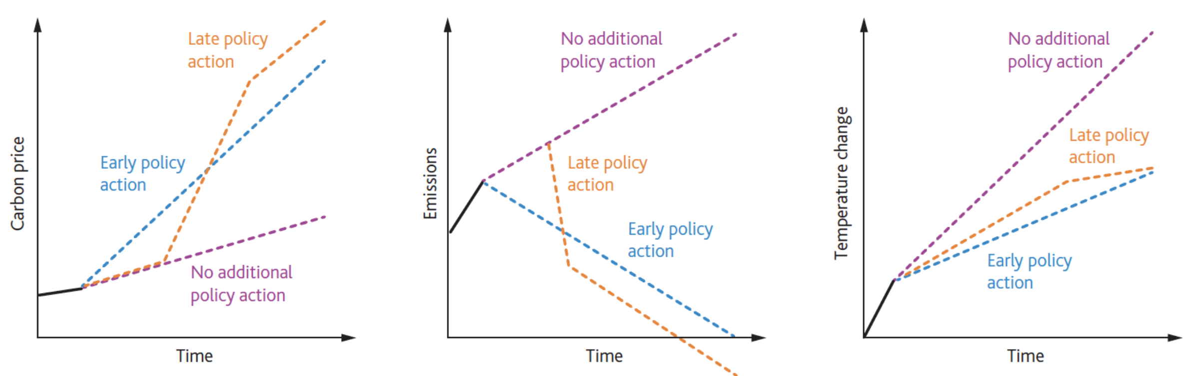


Figure 3: Illustrative variable pathways for alternative scenarios. Figure taken from Bank of England (2019).

Of course, these are merely examples. As Allen et al. (2020) and NGFS (2020) make evident, a richer collection of scenarios are often valuable, including ones with more sectoral specificity. Nevertheless this example is sufficient to illustrate some important considerations. While the pathways depicted in Figure 3 are specified as deterministic functions of time, there are overlapping components to the trajectories with subsequent branching at dates along the way. Such scenarios seem to suggest a dynamic structure with *ex ante* uncertainty that at least gets partially resolved at the branch dates. The branching structure has a feature that is familiar from other settings; but to conceptualize this formally, it becomes pertinent when it is known which branch will be followed. In other words, is path the beyond the branching really known *ex ante* or will it be revealed in the future? As we look over longer horizons, the potential number of branches would quite possibly increase along the way. In other words, uncertainty often compounds over time in financial market settings.

Recursive or dynamic programming type methods are well suited for studying compounding and other related phenomenon, provided we embrace a Markov specification for the stochastic dynamics. Robust counterparts of the type discussed in Section 4 are applicable but often presume that we formally put some bounds on the potential probabilities we are willing to entertain. It provides a way to depict formally a sensitivity analysis with a low-dimensional representation parameterized by how averse the decision maker is to uncertainty. In its extreme form, it can lead to simplistic worst-case analyses devoid of probabilistic considerations. However, it would be unwise for economic policy to push the financial institutions or the businesses that they transact with to such an extreme. How then are policy makers expecting regulated institutions to respond to scenarios specified devoid of probabilities?

Let me describe what might be two coherent uses of scenarios by central banks, while noting the shortcomings that I see with each. First, financial institutions regulated by central banks face potentially complicated dynamic decision problems in the face of uncertainty. Their actions in the future will be shaped in part by information that becomes revealed, including information pertaining to the exposures to climate change. They will necessarily face the uncertainty tradeoff that I made reference to. While there are many possible realizations of an uncertain future, the stress tests choose a few of these. Provided that the institutions give credible answers to how they respond consistent with their overall planning, then the results could have meaning for both the regulated and regulator. Even though the financial institutions face challenging decision problems for which dynamic considerations are paramount, the central bank need Darreonly to ensure credible answers to the posited scenarios and their associated pathways. I have two reactions to this defense. If, in the case of climate change, probabilistic reasoning along with dynamic information revelation is so difficult that central banks seek to avoid such considerations, how do they expect credible responses from the institutions that they regulate to their tests? In addition, how do central banks come up with interesting, but potentially unusual, scenarios without thinking through how uncertainty might play out in financial markets and the macroeconomy in dynamic ways? Both concerns are all the more severe when we entertain uncertainty over long horizons.

A second mathematically coherent use of scenarios is to ask the regulated financial institutions to use each scenario as a conditioning event. That is, inquire how financial institutions will behave conditioned on each of the scenarios. Central banks themselves could assign or speculate about probabilities over the different scenarios, but the conditioning effectively allows for scenario-by-scenario responses. While providing formal mathematical cover, the conditioning undermines the substantive value of the scenario analysis. Since each scenario contains a set of paths for economic, financial and policy variables for up to thirty years, the conditioning on a path provides an extensive and unrealistic picture of the future. Essentially, each scenario implies an incredible omniscience along some dimensions. This opens the door to responses that are constructed to look prudent along the pre-announced scenarios either explicitly or inadvertently with little regard to how this is integrated into a more comprehensive approach to uncertainty management. Including more scenarios will only scratch the surface in addressing the defects in this approach to financial stability polity. The approach is far removed from the dynamics of information revelation and the more interesting contingent decision making that the financial institutions are engaged in. A more interesting use of conditioning is to allow for information revelation at different branching dates along alternative trajectories. This would naturally lead to construction of a much more extensive set of scenarios with the inclusion of intermediate branching points to feature within trajectory uncertainty. This approach can lead to more meaningful outcomes when the regulator and regulated embrace probabilistic reasoning perhaps with imprecise specifications of the probabilities.

I turn again to decision theory under uncertainty to help us speculate about private sector behavior even to assess the prudence of such behavior in the role of regulator or supervisor. As I have argued, decision theory has value in both conceptualizing and quantifying how decisions depend on a tradeoff between best guesses and possible bad outcomes. The institutions that central banks monitor or regulate and businesses that they transact with must confront uncertainty tradeoffs in ongoing ways, however challenging that might be in the case of climate change.

A different (idealized) proposal for the construction and use of scenarios is as follows: let financial institutions determine a set of contingency plans or recursively specified decision rules meant to perform well over a wide range of possible scenario trajectories. The differing trajectories could include alternative branches and an associated information structure for information revelation. Such a plethora of trajectories would compel private sector institutions to confront uncertainty without being pushed to the non-probabilistic extremes of decision making. It would leave or offload a hard measurement-modeling challenge to the private sector, which is arguably a virtue. Central banks could then investigate collectively how these plans behave under even a small number of alternative scenarios of the type they find to be of particular interest. However, for this to give revealing information to an external observer, it would be important that the private sector NOT condition on a small set of scenarios when charting their course of action going forward.

While conceptually appealing, this approach is currently not practical. It would be quite a burden on both the regulator and regulated to share and verify such contingency rules, especially as knowledge of climate change uncertainty may evolve dynamically. Moreover, the regulator would need to rely on models of climate change and equilibrium valuation and policy responses to capture investor responses to price changes. Some simplifications will most definitely be necessary, and some compromises would have to be made relative to this idealized proposal. The dynamic perspective also raises important issues as to how effectively regulators can trust the stated dynamic commitments by the private sector actors. It is better that such issues be out in the open than disguised by more static perspectives.

More generally, there is much scope for devising clever and revealing approaches to stress testing that are more model-based and use nontrivial bounds on probabilities in their formulation. While I see the potential benefits to such an approach, the cost it imposes on the private sector participants must also be considered in its design and execution. Unless central banks evaluate the prospective private sector behavior across a rich array of dynamically specified scenarios, I fail to see how the stress testing can effectively sidestep the omniscient conditioning embedded in each of these scenarios. While this conditioning may not be at the extreme level that I described earlier, we should expect that the particular scenarios used by regulators will command more attention by the regulated going forward.

As I noted at the outset of this section, there may be virtue to having central banks push regulated financial institutions to assess their exposures to climate change over multiple decades as part of their long-term planning. But there are also reputational costs to overselling what can be learned from the currently conceived stress tests designed for thirty year horizons. Rethinking in a fundamental way the design and execution of such tests could lead to improved oversight in the future. In so doing, it would be better to embrace decision theory under uncertainty and its consequences in dynamic environments than to run from it.

6 Green, Vulnerability and Market Neutrality

In addition to carbon pricing and related policies, there is an important role for fiscal policy to invest in research and development of technologies that can accelerate the transition to a green economy. There are interesting conversations to be had about how to structure such investments in ways that spend public revenues wisely. When it comes to governments handing out money, discussions about how best to do this can get diverted by politicians only too willing to engage in "home bias" when assessing the value of such investments. Nevertheless, shifting what should be fiscal policy into the realm of monetary policy to add distance from the political arena has three important limitations: first, the tools of monetary policy are not nearly as potent as those of fiscal policy to address the need for green-oriented research and development or, more generally, to confront climate change. Second, such a shift could pull monetary policy under an even closer watchful eye of politicians in the future unless it is clearly part of some well-understood mandate. Third, it moves central banks into an arena to which their current expertise is limited.

In their initial call to action, NGFS (2019), one of the NGFS (Network for Greening the Financial Sector) contributors' recommendations is as follows:

> Acknowledging the different institutional arrangements in each jurisdiction, the NGFS encourages central banks to lead by example in their own operations. Without prejudice to their mandates and status, this includes integrating sustainability factors into the management of some of the portfolios at hand (own funds, pension funds and reserves to the extent possible).

Similarly, the BIS publication by Bolton et al. (2020) includes the argument:

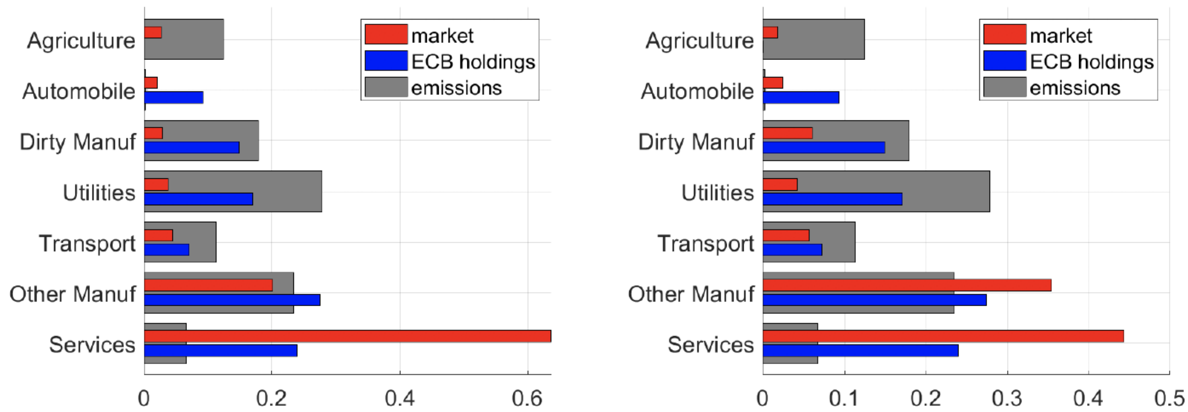
> Beyond approaches based strictly on risks, central banks and supervisors can help disseminate the adoption of so-called environmental, social and governance (ESG) standards in the financial sector, especially among pension funds and other asset managers.

Interest in ESG-based portfolios has been increasing substantially and notably over time.[13] Indeed, some investors may be willing to forgo a portion of their financial returns in exchange for assurances that some of the funds they invest in satisfy ESG standards. But I see little reason why such investors should rely on central banks to certify the extent to which businesses or funds meet ESG standards. Nor is it apparent that central banks have the expertise to fulfill this role in a credible way. ESG interested investors will look for profitable investments after accounting for the fund-specific attributes they find to be attractive. Quantifying and assessing portfolio assets can be done more effectively by the private sector as they would have a clear incentive to do so. If there are gains to collective knowledge sharing, then, presumably, fund managers would be willing to make their own assessments of fund worthiness or to contract with experts to achieve this outcome. Why should we ask central banks to provide this expertise? One argument could be that existing ESG standards are too nebulous and central banks should step in and police ESG fund claims. But the evidence that this is the best way to support green investment and transition towards net zero carbon emissions is at best weak. In addition to Matos (2020), see Elmalt et al. (2021) for recent research suggesting that ESG investment has little consequences for mitigating

[13] See Matos (2020) for a comprehensive discussion of ESG investment.

climate change. The more ambitious and direct approach to shifting investor incentives for the potential benefit of society fits squarely in the domain of fiscal policy. In contrast to nurturing green investment, as I remarked earlier, there is a well-defined regulatory role for central banks to assess *vulnerability* to climate change of private sector ventures that are financed by banks.

There is a related issue connected to monetary policy that has more subtle implications. Especially since the financial crisis, monetary policy has been engaged in asset purchases as a version for "unconventional monetary policy." More than one essay could be, or actually has been, written on the extent to which this has been a successful approach over a sustained period of time. In this paper, I sidestep that question and focus on how such policy could or should be altered because of climate change. I will draw on insights from a very recent paper: Papoutsi et al. (2021). Arguments have been put forth that asset purchases should be constrained to be market neutral along with a simple rule for implementation. The simple rule followed by the ECB is to purchase corporate bonds in proportion to the amount of bonds outstanding. In their paper, Papoutsi et al. build a multi-sector model with a climate externality and financial frictions. They show that the ECB's simple rule is not market neutral in this model. Instead, ECB purchases favor firms that issue bonds; these firms tend to have more tangible capital as well as higher emissions. See Figure 4. Thus, slanting ECB corporate bond holdings to be more green is in clear conflict with the stated aims of market neutrality, for better or for worse. Finally, within the confines of their model, they solve a social planner problem in which carbon taxes set appropriately vitiate the need for investment slanting on the part of the planner. It is only in a second-best world without carbon taxation where portfolio slanting is needed to improve social welfare. Their analysis illustrates how portfolio slanting practiced by monetary authorities can be a weak substitute for fiscal policy that taxes carbon emissions.



(a) Market measured by capital income (b) Market measured by total assets to revenues

Figure 4: Sector shares of the market portfolio, ECB holdings and emissions. This figure is constructed using the year-end 2017 data. In panel (a), market shares are measured as capital income by sector (capital income = value added - wages). In panel (b), market shares are measured as output (from Eurostat) times the ratio of total assets to revenues (from Orbis) by sector. Emissions intensity is measured by Scope 1 air emissions by sector. The ECB portfolio includes only securities held under the corporate sector purchase programme (CSPP) that was initiated in March 2016. By construction, all sector shares sum up to one. Data sources: SHS (ECB), Orbis and Eurstat. Definition of sectors: Dirty Manufacturing includes: oil and coke, chemicals, basic metals, nonmetalic minerals manufacturing; Other Manufacturing includes: food, beverages, tobacco, textiles, leather, wood, paper, pharmaceuticals, electronics, electrical equipment, machinery, furniture, construction, and other manufacturing. This is Figure 1 from Papoutsi et al. (2021).

I find a more proactive role in green investment to be all the more problematic. While green capital investment can be socially productive, specific investment projects will likely be encumbered with uncertainty. To navigate this uncertainty successfully requires expertise outside the realm of central banking. I fail to see the virtue or justification for pushing central banks into the role of being green venture capitalists. A more productive approach would restructure incentives for prudent private sector investment via fiscal policy.

7 How do Climate Change Challenges differ from other Natural Disasters?

An important consideration when comparing climate change to other natural disasters is the time frame over which the uncertainty will play out. Climate change may be special because of the relatively long time horizon of interest. This is in sharp contrast to the advent of the COVID pandemic in which both economic and policy responses played over days and weeks.

Central banks have a mandate for the provision of liquidity, sometimes taking the form of lender of last resort. We have seen the need for such flexibility both in the handling of the 2007-2008 financial crisis and the advent of the COVID pandemic. These are examples of situations when rapid responses are critical to the functioning of financial markets and the provision of liquidity necessary to avoid unproductive market freezes. The pandemic, in particular, is a natural disaster that triggered the need for *ad hoc* decision making under limited information. Other natural disasters in the future may well trigger the need for similar responses.

Currently, climate change does not seem to pose a challenge of this nature. Climate change uncertainty would seem better conceived of as playing out over multiple years or decades instead of a rapid acceleration unfolding over days and weeks. This difference is clearly reflected by the decision of some central banks to run stress tests with thirty-year horizons.

In the future, could climate change conceivably catch us by complete surprise and trigger a liquidity crisis? As I mentioned before, some models of climate change include tipping points that may cause a major disruption in the future that unfolds quickly. The important question pertains to the extent of whether there will be early warning signals. How far in advance might we have strong signals about the impending disaster? Additionally, climate change could trigger more localized or region-specific problems for which a rapid strike of central bank policy could be helpful. Our hope is that the development of cleaner technologies coupled with prudent policy outside the realm of monetary policy can help us avoid even this possibility.

8 Conclusion

Climate change is an important challenge for policy. Fiscal policy has some levers that can truly have an impact, including taxation of carbon emissions or subsidies for research that aids the development of new technologies that pose much less of a threat to the environment. How best to develop and use quantitative research to guide fiscal policy in the face of uncertainty remains a fertile avenue for future research. Monetary policy can support these objectives and promote sound strategies for quantifying longer term impacts of exposure to climate change uncertainty. Indeed, there will be societal benefits that will accrue for this that can be mutually beneficial for financial institutions as well as central banks in their role of monitoring a broadly-conceived banking sector. On the other hand, monetary policy is a weak substitute for sensible fiscal policy. Central banks that overstate their ability to contribute run the risk of both losing their distance from the political arena and providing false hope for a public looking for how best to tackle climate change.

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