# Green Financial and Regulatory Policies: Why Are Some Central Banks Moving Faster than Others?

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## Abstract

Climate change poses financial risks to individual firms and is a source of systemic risk to the stability of financial systems. Central banks are emerging as key state actors in environmental governance to tackle these risks, implementing policies encompassing regulatory oversight, credit guidance, and the greening of prudential regulations. The diffusion of these policies across countries is at various stages of deliberation and implementation. In this context, this article uses a newly constructed index measuring the intensity of green financial and regulatory policies imposed by central banks of various developed and developing countries from 1996 through 2018. We empirically assess whether central banks in countries that are more vulnerable to climate change are more likely to be implementers of these policies and find robust evidence in support of our hypothesis.

**Keywords:** central banks, climate risk, financial stability, prudential regulations, green finance

Climate change and environmental degradation affect the economy in far-reaching ways, including significant implications for financial stability and the future profitability of commercial enterprises. Described as an intractable super-wicked problem (Levin et al. 2012), climate change is a negative externality that poses a systemic or "green swan risk" with a potential to catalyze "the next systemic financial crisis" (Bolton et al. 2020, iii).[1]

The climate finance and economics literature has outlined two broad ways in which the macroeconomy in general and the financial system in particular could be affected by climate change. First, a "physical risk" arises from sudden and unpredictable climate episodes (such as extreme weather–related events or climate-related disasters), manifesting as negative supply- and demand-side shocks to

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1. Extended from the concept of "black swan"—events that are unexpected and difficult to account for in risk-based accounting, have wide-ranging and extreme impacts, and are rationalized ex post (Taleb 2010). Green swans have two additional characteristics: there is unanimity on their eventual occurrence, though the timing is unknown, and they will have catastrophic and irreversible consequences (Svartzman et al. 2020).

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output and prices and adversely impacting the balance sheets of households and firms in a nondiscriminatory manner (Dafermos et al. 2018; Molico 2019).

Second, a "transition risk," posed by the speed and manner of the decarbonization process, can precipitate fundamental misalignments in asset prices of high- and low-carbon sectors, thereby resulting in massive volumes of "stranded assets,"[2] which in turn could compromise the stability of entire financial systems.[3] These risks could materialize due to an unexpected—or expected but unplanned-for—shift in the current carbon emission standards (Schoenmaker and Van Tilburg 2016) or policy changes that penalize high-carbon investments, technological breakthroughs that increase green energy production, and large-scale shifts in consumer preferences toward more environment-friendly technologies and products.[4]

Both physical and transition risks compound various existing financial risks to firms, including credit, market, liquidity, operational, and reputational risks (Gruenewald 2020; Pointner and Ritzberger-Grünwald 2019). For instance, as the balance sheets of financial entities deteriorate in the aftermath of extreme weather events (an example of physical risk), their profitability and ability to service their debt decrease, thereby increasing their credit risk. Credit risk can also be exacerbated for firms in high-carbon sectors due to a "hard landing" or a messy and disorderly transition from a high- to a low-carbon economy since it will cause an abrupt price correction (devaluation) in the value of carbon-intensive assets. From a systemic perspective, physical risk can directly or indirectly impact financial stability as the financial system bears huge losses arising from increased liabilities, insurance claims, and bankruptcies in the aftermath of extreme weather events. Likewise, an abrupt decarbonization process could inflict serious damage on financial stability as it affects large-scale corrections in asset prices and leads to the economy-wide problem of "stranded assets."

Despite the foreseeable risks to financial stability arising from climate change, policy actions to minimize these risks have lagged until recently. A multilevel and multipronged policy response has been emphasized to tackle the various market failures associated with climate change. At the international level, this entails participation of and negotiation among national veto players of various jurisdictions to arrive at global agreements on carbon pricing and transfers from developed to developing countries to undertake climate mitigation policies (Skovgaard 2012). At the domestic level, it necessitates a mix of green fiscal and financial policies to incentivize investment in low-carbon

2. Arising from misalignments in fossil fuel assets and their eventual write-down brought about by a transition to greener energy sources (Mercure et al. 2018).
3. A slightly different but associated transition risk also arises from the large-scale investment flowing into green and ESG (Environment Social and Governance investing)-compliant stocks, which has led to concerns about both a possible overvaluation of these assets ("green bubbles") and/or a misplaced trust in their green-ness, or "greenwashing."
4. A third related risk, called liability risk, arises specifically for financial entities like insurance agencies and businesses due to mounting compensation claims following climate-related disasters. Liability risks tend to arise as a consequence of physical and transition risk.

sectors while mitigating economic and financial risks from the transition process. Several highly developed economies have embarked on green industrial policies to facilitate the transition to a low-carbon economy (Meckling 2021).

On the latter front, central banks and financial supervisors have also emerged as key policy actors articulating the impact of climate change on the macroeconomy in terms of growth and productivity and on financial-sector soundness—at an institutional level but especially with regard to systemic risks to the entire financial system, encompassed under the umbrella of "green central banking" (Mauderer 2019; Schnabel 2020; Villeroy de Galhau 2020). Green central banking broadly aims to include climate change as one of the risk factors when conceptualizing financial risk models as well as charting a path toward a more sustainable growth trajectory.

Across the spectrum of central bank climate policy options, green financial and regulatory policies have emerged as one of the most popular and largely noncontentious responses[5] within their current de jure mandates to tackle climate change. These policies seem well suited to tackle climate change–related financial risks (CRFRs) occurring both within individual financial entities and at the system-wide level. The introduction of these policies across countries is a fairly recent phenomenon, and their effectiveness in mitigating CRFRs can only be judged over time.

In this article, we are interested more narrowly in examining the differential intensity of implementation of these policies across countries, using a subsample of countries that have thus far adopted these policies. Among these early adopters, this article examines whether countries that are more vulnerable to climate change tend to more intensively adopt green financial and regulatory policies.

The remainder of the article is structured as follows. The next section provides a brief overview of central banking theory and evolution, discussing the progression of reforms over time and describing their agency or action in climate change thus far, with particular emphasis on the greening of financial policies. The third section discusses the methodology followed in this article and provides details of the empirical model. The fourth section describes the data used in the empirical analysis. The fifth section presents the results and their discussion, and the final section concludes.

## Central Banks and Climate Change

### *Theory of Central Banking and Its Evolution*

The existence of central banks, along with the venerated ideal of central bank independence (CBI), is primarily rooted in the time inconsistency problem

5. Among other responses, criticisms have been mounted particularly against the "greening" of monetary policy (Brunnermeier and Landau 2020; Cochrane 2020; Honohan 2019) on grounds that it leads central banking too far away from its legal mandate and risks compromising the independence and political neutrality of central banks.

faced by politicians (Bernhard et al. 2003).[6] Therefore vesting monetary powers in an independent and apolitical institution such as a central bank is advantageous insofar as it enhances credibility toward inflation targets and helps in anchoring inflation expectations. Viewed from a principal–agent framework, governments as principals delegate monetary power to central banks as agents, with the extent and nature of this delegation accounting for the differences and constraints faced by central banks across countries.

Romelli (2022) investigates the drivers of change in central bank design across 154 countries from 1972 to 2017 using a new self-constructed data set. Other than political and economic factors, he demonstrates that changes in levels of CBI are both self-perpetuating (based on past levels of CBI) and determined by forces of emulation and learning from other (neighboring or regional) countries as well as engagements with international organizations like the International Monetary Fund (IMF). Moreover, for some countries, CBI evolves endogenously, prompted by periods of crises or shocks and high inflation that necessitate the creation and enhancement of central banks as independent entities.

Over the decades, central banking has undergone several waves of reforms—beginning with an increased emphasis on CBI, followed by the evolution and diffusion of an inflation-targeting regime across countries. The addition of financial stability as an explicit central bank mandate succeeded a spate of financial crises and culminated in the 2007–2008 housing bubble crash. Recently, discussions around the inclusion of broader social, environmental, and climate change concerns in central bank policy making have emerged.

### *Central Bank Intervention in Climate Policies*

Central bank intervention in climate policies has been characterized as a "sudden paradigm shift" (Langley and Morris 2020)[7] with some concerns of "mission creep," insofar as it leads them to overstep or expand their mandate too far (Cochrane 2020; Hansen 2022). In practice, while some central banks—such as the European Central Bank (ECB) and individual central banks in the European Union and Asia—have been proactive both in articulating climate risks and in undertaking concerted policy action to minimize these risks,[8] others—most

6. This problem arises from the perverse incentives faced by politicians wherein they can artificially boost employment and output at politically opportune times (such as impending elections) by temporarily increasing the money supply. However, a greater money supply feeds into higher inflation over time, compromising macroeconomic stability and, inevitably, growth in the long run. Politicians, thus, are unable to maintain credible commitments regarding the level of inflation, leading to higher inflationary expectations over time, which ultimately renders monetary policy ineffective.
7. We thank an anonymous reviewer for highlighting this issue.
8. Anecdotally, while the ECB has been the most vocal in articulating the impacts of climate-related risks on financial stability (Lagarde 2021; Schnabel 2020), emerging economies in Asia and Latin America have been first movers in implementing green financial and regulatory policies (Dikau and Ryan-Collins 2017).

notably, the US Federal Reserve—have been reticent, arguing that climate policy making is beyond their mandate and should be entrusted to elected officials.

What are the possible channels through which higher climate risks can translate to greater central bank policy action? Broadly speaking, two sets of factors could motivate policy responses by central banks, namely, internal factors emerging from within the central banking community and external forces, actors, or events that compel central banks to respond. Within the first category, one of the foremost factors is their de jure mandate, which determines their scope of action (Dikau and Volz 2021).

However, not all central banks are equally constrained by their mandates (Masciandaro and Tarsia 2021). For example, even though the ECB has been tasked exclusively with preserving price stability[9], its president, Christine Lagarde, has frequently reiterated the need for central banks to take climate risks into account while setting monetary and other supervisory policies, given the long-lasting impact of climate phenomena on real economic variables and the market power of central banks in facilitating green finance to enable a smooth transition to net zero (Lagarde 2021).[10]

Aside from de jure mandates constraining or enabling central banks' agency, the role of actors/individuals within these institutions has been significant in steering central bank policies toward inclusion of climate risks. For instance, former Bank of England governor Mark Carney's speech in 2015 on climate risks posed to the United Kingdom's insurance sector has been hailed as a turning point in initiating discussion within the central banking community on climate risks and their impact on system-wide financial stability. He argued that, akin to the "tragedy of the commons" surrounding the resolution of public goods, policy makers are unable to take decisive and significant action on climate change because they encounter a "tragedy of the horizon"—referring to an inability to envisage the serious consequences of climate change during their lifetime or term of office (Carney 2015). Similarly, the ECB's shift of focus toward green central banking around 2019 has coincided with Lagarde's appointment as president.

Simultaneously, external forces, such as the broader sociopolitical environment of the country, could also exert pressure on central banks to act, influencing their "green sensibility."[11] Public opinion, their perceptions about climate change, and their support for different climate policies, in particular, may directly affect the type of climate mitigation policy tool eventually

9. The ECB does have a secondary mandate to "support the general economic policies in the European Union", "without prejudice to the objective of price stability" (Available at: https://www.ecb.europa.eu/mopo/intro/html/index.en.html, last accessed April 13, 2023). This is laid out in Article 127(1) of the Treaty on the Functioning of the European Union.
10. Similar arguments have also been made by academics and other central bankers (Boneva et al. 2022; McKibbin et al. 2017; Rustler 2019; Schnabel 2020; Schoenmaker 2021).
11. Green sensibility refers to central banks' participation in a gamut of climate-related policy-making initiatives and announcements/intentions of future initiatives (Masciandaro and Tarsia 2021).

implemented (Bumann 2021; Drews and van den Bergh 2016; Huber et al. 2020).[12] However, since central bankers are unelected technocrats who are not accountable for their policies to the general public, they are not directly impacted by public opinion. Rather, politicians mediate the pressure exerted by the public on central banks through a two-tier principal–agent framework (Masciandaro and Tarsia 2021).

External pressure on central banks to act may also have arisen in a top-down manner through elite networks and peer emulation. There is an emerging policy science literature that highlights the significance of policy diffusion among countries through the channels of learning and emulation in accelerating the uptake of carbon pricing policies (Linsenmeier et al. 2022; Raghoo and Shah 2022; Thisted and Thisted 2020). Central bankers have also engaged in substantial international cooperation and capacity-building initiatives to share knowledge and expertise on incorporating climate risks to the macrofinancial system through macroeconomic frameworks, econometric modeling, and financial policies. These include the Network for Greening the Financial System, the Taskforce on Climate-Related Financial Disclosures constituted by the Financial Stability Board, and the Taskforce on Climate-Related Financial Risks established by the Basel Committee in 2020, among others. Being a close-knit epistemic community of like-minded individuals with a niche expertise (Haas 1992), membership in these bodies could also play a role in the diffusion of green financial policies across countries.

## *Greening of Financial and Regulatory Policies*

The job of financial supervisors and central banks to mitigate the impact of CRFRs on financial stability is both preventive (in terms of "nudging" financial entities to shift their lending focus away from carbon-intensive assets) and mitigative (to facilitate a "soft landing" from a high-carbon to low-carbon economy in the medium term). Green financial and regulatory policies serve both these purposes, as they are specifically designed to nudge investors toward investing in green technologies and away from high-carbon assets, while also mitigating systemic risks to overall financial stability by preventing the buildup of excessive risk within either of the two types of investments.

In this article, we define such policies as ones that encompass regulatory oversight by central banks and/or financial supervisors over climate and sustainability issues, credit guidance on loans to sectors based on their carbon emissions footprint, and the greening of prudential regulations (aligning traditional micro- and macroprudential policies with a climate objective). These policies have increasingly become a component of central banks' tool kit in responding

12. This is, in fact, one of the reasons why a higher price on carbon or taxes on high-carbon sectors/polluting activities have not been forthcoming, since they lack widespread public support and are politically unpopular (Bergquist et al. 2022).

to CRFRs and focus on the incorporation of environmental and social safeguards by individual financial entities to ensure their resilience to climatic risks.

Although data on the status of implementation of these policies and the policy tools used are still very limited, we make use of the Green Monetary and Financial Policies (GMFP) Tracker by the E-axes Forum,[13] which lists the type of policy and year of implementation for a selected set of countries from 1995 to 2021. The GMFP Tracker enumerates the financial, monetary, and additional policies implemented by countries to tackle climate change–associated risks to monetary and financial stability. Among these, we focus only on financial policies, since they are specifically geared toward mitigating risks to financial stability manifesting through the physical and transition risk channels.

Financial policies in the index include three policy tools, namely, credit guidance policy, prudential policy, and supervisory policy. Of these, credit guidance policy entails the preferential allocation of credit to green sectors of the economy through a priority sector lending scheme. Prudential policy includes only one microprudential tool, namely, preferential green capital requirements. Among the last subset of financial policies, supervisory policy subsumes four policy tools. These include surveys of practices on climate risk exposure and management by financial institutions, supervisory expectations and guidelines to financial institutions on the management of climate-related risks, climate-related disclosure requirements from financial market participants, and climate stress testing.

Of those countries that have implemented green financial policies either mandatorily or voluntarily for firms, supervisory policies emerge as the most popularly used class of policy tool, within which supervisory expectations are implemented most often. These policies, along with enhanced disclosure requirements for financial market participants and surveys of practices undertaken by firms to align their businesses with sustainability objectives, underpin the feasibility and effectiveness of all other green financial measures.

Climate-related stress testing is another popularly implemented supervisory policy tool that aims to incorporate the impact of climate-associated risks into the risk assessment frameworks of regulatory authorities (Brunnermeier and Landau 2020). It is a preemptive measure to gauge the extent and severity of climate risks so that financial institutions can frame appropriate policy responses. Climate stress tests are currently being undertaken in several countries, such as Brazil, Hong Kong, Japan, Singapore, the United Kingdom, and some European countries (Kyriakopoulou et al. 2020). Various other countries are actively considering proposals to include climate-related risks in their risk assessment frameworks through stress tests as well as scenario analysis. Other green financial measures used include credit guidance policies, such as differential lending requirements and sectoral lending limits for low-carbon versus high-carbon assets. Since directed lending as a policy tool is confined mostly

13. Available at: https://www.e-axes.org/about/, last accessed April 10, 2023.

to use in developing countries, these policies are currently being implemented in some Asian and Latin American countries (Campiglio et al. 2018).

## Empirical Model and Methodology

Having offered a brief discussion of the various green financial policies currently implemented or proposed, in this section, we empirically examine the determinants of green financial policy intensity across countries using a specific-to-general approach. In the baseline, we consider the simplest form of a bivariate regression between green policy intensity and climate vulnerability using a two-way fixed-effects model. We conjecture that the susceptibility of a country to climate risks is likely to be a crucial factor determining the intensity of action and resolve by various policy makers (including central banks) to undertake climate change mitigation and adaptation initiatives.

Having established the baseline, we contend that several other variables could also impact the uptake of green financial policies. To test whether climate vulnerability is a significant determinant of green financial policy intensity, we run an extended model, controlling for various determinants of financial stability and the imposition of prudential policies, informed by previous literature (Ademuyiwa et al. 2018; Baskaya et al. 2016; Boar et al. 2017; Egawa et al. 2015). This includes a country's institutional capacity, its level of economic development, economic size, capital openness, and private-sector credit, among other factors.

The literature suggests that economically larger and more developed countries are less likely to entrust central banks with the management of macroprudential policies. Since green financial policies are an extension of conventional financial or macroprudential policies aimed at preserving financial stability, this would suggest a low intensity of green financial policies in such countries as well. The impact of inflation on the imposition of green financial and regulatory policies is less clear-cut. On one hand, a low and stable inflation level could work in favor of central banks, increasing their credibility and allowing for a transfer of more functions, such as the preservation of financial stability, to them. On the other hand, if the central bank's mandate is explicitly and solely premised on price stability, this could detract from awarding it additional functions, such as devising prudential policies for financial stability.

We also include a range of financial and external-sector variables to proxy for the level of financial development and openness of a country, such as the volume of credit extended to the private sector, level of international reserves, ratio of bank deposits to gross domestic product (GDP), ratio of central bank assets to GDP, and level of financial account openness of a country.

Credit extended to the private sector as a percentage of GDP and the ratio of bank deposits to GDP proxy the extent of financial-sector development of a country. Similarly, the ratio of central bank assets to GDP is a proxy for the relative significance of the central bank in the economy and the degree of CBI. While financial development proxies are generally considered important

controls insofar as they impact central bank policies and actions, their impact on green financial policies can a priori go in either direction. First, a higher level of financial development is likely to create more fertile ground for implementing green financial policies, given that well-established private markets and firms are the direct recipients of these regulations.[14] Second, a higher level of financial development or deeper financial markets in a country signify a greater risk-absorbing ability for climate-induced financial risks, which reduces the necessity to implement green financial policies. Third, some financial and prudential policies, such as credit guidance, have historically been used more commonly by economies with less market-based or sophisticated financial systems with a history of financial repression.

Among external-sector variables, we include a country's level of international reserves and its capital account openness as possible determinants of green financial policies. Higher international reserves signify a lower susceptibility to the adverse effects of external-sector shocks, including those arising from cross-border effects of climate risks, thereby reducing a country's need to resort to green financial policies. On the other hand, higher capital openness makes a country more vulnerable to macrofinancial shocks, including systemic risks arising from climate change, making these countries more likely to implement green financial policies. Thus the overall impact of external-sector variables is ambiguous.

Our general model specification is as follows:

$$\text{GreenPolicy}_{it} = \alpha_{it} + \beta X_{it} + \delta Z_{\text{it}} + c_i + m_t + \varepsilon_{it}. \quad (1)$$

Respectively, $\text{GreenPolicy}_{it}$ is an ordinal variable indicating the "intensity" or number of green financial policies implemented by country $i$ in year $t$ (see the next section, on data); $\alpha_{it}$ is a constant; $X_{it}$ is the vulnerability of a country to climate change, our key independent variable; $Z_{\text{it}}$ refers to the controls used in our extended model; $c_i$ and $m_t$ are country and time fixed effects, respectively; and $\varepsilon_{it}$ is the error term.

To compare the relative economic significance of these determinants on green financial policies across the board, we estimate coefficients of fixed-effect regression models with standardized variables.

## Data Description

### *Policy Intensity of Climate Regulatory Policies*

To create the policy intensity index, we considered all financial policies included in the E-axes Forum's GMFP Tracker (including credit guidance, prudential, and

14. Boar et al. (2017) find that the degree of capital openness of a country and its financial development mediate the impact of macroprudential policies on long-run economic performance. Baskaya et al. (2016) demonstrate the significance of financial development in determining the effectiveness of different types of macroprudential policy tools (price based or quantity based).

supervisory policy). We then created an ordinal index ranging from 0 to 12 based on the number of green financial policies implemented by a country in successive years, beginning from 1995. If a country had no green financial policy in a particular year, it was assigned a score of 0. Subsequently, if a country implemented any financial policy in a particular year, its score was incrementally adjusted by 1. The method of construction of the policy intensity index—based on the number of green financial policies implemented by a country over time—is useful for a nuanced analysis of determinants of these policies, as opposed to the more simplistic alternative of creating only a dichotomous variable to illustrate whether a country has a green financial policy and is also consistent with previous studies in the literature, such as the macroprudential index developed by Cerutti et al. (2017).

At the outset, we acknowledge the shortcomings inherent in our simple counting method to aggregate across different policy types and tools, particularly given that some policy interventions may have a higher impact compared to others (especially policies aimed at supervisory guidance). However, since the greening of financial and regulatory policies is a recent phenomenon, comprehensive, high-frequency, and reliable data on their discussion and implementation are scarce. To the best of our knowledge, our index constitutes one of the first efforts to utilize the E-axes database and initiate empirical research on the drivers and effectiveness of green financial policies.

In addition, given the nascent nature of these policies, though green financial policy tools are not homogeneous or perfect substitutes, their uptake by central banks has a signaling effect (signaling their resolve to initiate or step up the incorporation of climate risks in central banking), in addition to their direct impact on preserving financial stability threatened by climate physical and transition risks. Insofar as the signaling effect is considered, we can assume that each of the policy tools is equally important.[15]

Our final data set used for empirical analysis contains nineteen economies.[16] The relatively limited number of countries in our sample results from two factors. First, only very few central banks have implemented green financial and monetary policies thus far, and our research is confined to these early adopters. Second, the E-axes database, which represents one of the first efforts to aggregate reliable cross-country data on green financial policies, is a recent endeavor that is still being continually updated. Consequently, the data for our empirical analysis are conditional on those central banks that have already

15. In fact, even in the slightly more established literature on the drivers of adoption of macroprudential policies and their effectiveness, the most widely used index developed by Cerutti et al. (2017) aggregates across twelve different lender- and borrower-based macroprudential policy tools. Even this literature to date in this field has been focused more on analyzing the nexus between monetary policy and different macroprudential policy tools, rather than attempting to compare between various macroprudential policies themselves (Mester 2017; Svensson 2018).
16. Australia, Brazil, Canada, China, Denmark, France, Germany, India, Indonesia, Italy, Japan, Mexico, the Netherlands, Norway, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

adopted these policies, and our research question aims to address whether a higher level of climate vulnerability is correlated with a greater intensity of adoption of green financial and regulatory policies within this purposive sample of countries.

On average, countries in our subsample have implemented one green financial policy until 2018, with the United Kingdom having implemented twelve such policies progressively over the years, beginning from 2000. The most popular of these policies is guidelines or expectations set out by the respective financial supervisory authority on sustainability, climate risk management, or disclosure of climate-related risks, across both developing and developed countries. Developed economies have complemented these with other policies, such as surveys of practices and climate stress testing. Within Asia, China has been at the forefront of rolling out supervisory and disclosure requirements for financial and other private-sector firms, along with climate stress-testing pilots, although no results have been published so far. South and Southeast Asian economies like India and Indonesia have relied more on supervisory guidelines, along with credit guidance policies in the former (E-axes 2021).[17]

### *Proxies for Climatic Risk*

With regard to climate risk, we draw on Chen et al. (2015), who rank 182 countries on their level of vulnerability to climate change from 1995 through 2020 on the Notre Dame Global Adaptation Index (ND-GAIN). This is a composite index of an array of variables comprising two broad components—the vulnerability of a country to climate disruptions and the readiness of a country to mitigate their adverse impacts.[18] Their premise is that countries that are naturally more predisposed to suffering the adverse impacts of climate change by virtue of a higher vulnerability could nonetheless mitigate these to some extent by developing adequate capacity or "readiness" through both government and private-sector initiatives (Fankhauser and McDermott 2014). Owing to its time series nature and wide coverage, this has been cited as a key data source for

17. We make specific mention of the European Central Bank (ECB) in Supplemental Appendix A, since the EU region is unique in that it has both individual EU-country central banks and a supranational ECB at the regional EU level. We thank an anonymous referee for motivating this discussion.

18. We use the ND-GAIN data for measuring climate physical risks for two reasons. First, the longer time series nature of this index, from 1995 to 2019, allows for greater temporal coverage of our panel data, thereby increasing the statistical power and robustness of our empirical analysis. Most other climate risk indexes do not have a comparable period of data coverage. Second, that it is a composite indicator aggregating over seventy-four variables provides us with a wide array of forward-looking data, which yields a more accurate estimate of the susceptibility of a country to the acute and chronic impacts of climate physical risks. We are, however, mindful that the estimates produced by this index could be misleadingly precise (e.g., the vulnerability index being reported up to fifteen decimal points), and we thank an anonymous reviewer for drawing our attention to this shortcoming of the data source.

country-level measures of physical risks by the Financial Stability Board at the Bank for International Settlements (Financial Stability Board 2021) and the European Investment Bank (Ferrazzi et al. 2021).

Vulnerability of a country is operationally disaggregated into subcomponents of exposure, sensitivity, and adaptive capacity of a country, all measured across six crucial sectors exposed to climate change, namely, food, water, health, ecosystem services, human habitat, and infrastructure. The exposure component measures the extent of intrinsic or natural vulnerability of a particular sector to climate change due to physical factors. Sensitivity, on the other hand, measures the human impact of the aforesaid degree of exposure of a particular sector to the people or communities who depend on it. Lastly, adaptive capacity measures the sectoral ability to ameliorate potential damage resulting from climate change scenarios.

The other main constituent of ND-GAIN, namely, readiness, does not explicitly include climate-related readiness measures but focuses on more general economy-wide proxies that indicate the levels of economic, governance, and social resources of a country that can possibly be leveraged to enhance the country's resilience and minimize climate change impacts.

For our analysis, we focus only on the vulnerability component of the ND-GAIN index since we are interested in analyzing the impact of higher "gross" vulnerability of a country to climate change on the resulting intensity of green financial policies implemented. We use the aggregate measure of vulnerability as the key independent variable and its individual component "sensitivity" for checking the robustness of our results. Owing to statistical concerns of perfect collinearity in the fixed-effects model, we cannot use the exposure subcomponent.

Once we establish the baseline, we investigate whether other variables also affect the correlation. Here we use readiness as a proxy for the general institutional quality and governance of a country in a model with a full set of extended controls.

Apart from using ND-GAIN data, we also use the Climate Risk Index (CRI) prepared by Germanwatch, a narrower measure of climate vulnerability, as an alternative proxy for a country's climate vulnerability in our baseline bivariate regression for purposes of robustness.[19] The CRI identifies the extent to which 190 countries have been affected by extreme weather events in terms of fatalities as well as economic losses that occurred from 2006 to 2018. Each country's index score is derived from a country's average ranking considering four categories according to the following weights: death toll, one-sixth; deaths per 100,000 inhabitants, one-third; absolute losses in purchasing power parity (PPP) terms, one-sixth; and losses per GDP unit, one-third. The index score ranges from 25 to 172. As lower index scores indicate countries with higher risk, we reverse the values by subtracting from 200 for easier interpretation.

19. There are other indexes measuring climate vulnerability as well, such as the HSBC Climate Change Report (Paun et al. 2018) and the IMF's Climate Change Indicators Dashboard. However, we could not use these data due to their unavailability over a longer time horizon.

### *Other Variables*

As noted earlier, we include various other macroeconomic and financial variables in our extended model to verify the robustness of our baseline results and to examine mechanisms through which a higher vulnerability to climate change may impact the intensity of green financial policies (discussed in the section "Extended Model with Controls"). Summary statistics of all variables used in the analysis are presented in Supplemental Appendix B.

## Empirical Results

### *Baseline Results*

Our final subsample includes nineteen economies, based on data availability across various indicators included in the analysis. We start with a bivariate regression model establishing the relationship between vulnerability to climate change and the green financial policy intensity index. Results are presented in Table 1, columns (1) and (2).

As we can see, both the vulnerability and sensitivity indicators are positive and highly statistically significant at the 1 percent significance level. A standard deviation increase in the vulnerability of a country to climate change increases its green policy intensity by 3.5 standard deviations, whereas a standard deviation increase in sensitivity of a country raises its green policy intensity by 1.4

**Table 1**
Baseline Regression

| | *(1)* | *(2)* | *(3)* |
|---|---|---|---|
| Dependent variable: green policy | | | |
| Vulnerability | 3.482*** (0.544) | | |
| Sensitivity | | 1.427*** (0.337) | |
| CRI | | | 0.0802* (0.0408) |
| Constant | 0.822*** (0.237) | −0.113 (0.160) | −0.0333 (0.101) |
| Observations | 396 | 396 | 250 |
| $R^2$ | 0.396 | 0.358 | 0.480 |
| Country FE | yes | yes | yes |
| Time FE | yes | yes | yes |
| No. of countries | 19 | 19 | 19 |

All time fixed effects are omitted from reporting. Standard errors are in parentheses.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

standard deviations. This confirms our initial hypothesis that countries more vulnerable or sensitive to climate change impacts are more likely to implement green financial policies. Our results are robust to an alternative operationalization of a country's climate vulnerability, measured by the CRI developed by Germanwatch. From column (3) of Table 1, we see that the CRI coefficient is both positive and statistically significant at the 10 percent level, although the coefficient is rather small. Here a standard deviation increase in a country's vulnerability to climate change increases the intensity of green financial and regulatory policies by 0.08 standard deviations.

We surmise that one possible reason for the relatively small economic significance of the CRI coefficient may be the varying nature of construction of this index from the ND-GAIN measures of vulnerability and sensitivity. Whereas the CRI is a narrow measure of climate vulnerability that takes into account the ex post economic and humanitarian losses suffered by countries as a consequence of climate disasters, the vulnerability and sensitivity indicators are broader and more forward looking, estimating the susceptibility of a country to the acute and chronic impacts of physical climate risks, based on a composite set of thirty-six indicators. In this sense, the smaller size of the CRI coefficient thus suggests that central banks' and financial regulators' policies on climate change may be based more on forward-looking estimates of countries' susceptibility to extreme weather events and the more gradual sea level rise and less on the economic and humanitarian impacts of past climate disasters.

### *Extended Model with Controls*

While the bivariate analysis confirms a clear association between climate vulnerability and green financial policies, it may be potentially confounded by other omitted variables correlated with the dependent variable. To address this concern, we include a range of other variables that may impact financial stability, as well as determinants of the imposition of macroprudential policies (tasked with mitigating systemic risks to financial stability, which is also the objective of green financial policies), based on a survey of the existing literature. This includes general determinants like the institutional capability or readiness of a country, the overall size of an economy captured by its real GDP, its inflation level, and the level of economic development captured by real GDP per capita, along with a range of indicators measuring the level of financial development of a country, such as the ratio of domestic credit extended to the private sector, the size of central bank assets as a proportion of GDP, and the ratio of bank deposits to GDP.[20] Results are presented in Table 2.

From Table 2, we see that with a full set of controls, the coefficients on both vulnerability and sensitivity remain positive and highly significant, consistent

20. All data sourced from IMF (World Economic Outlook and *Balance of Payments Manual*) and World Bank (World Development Indicators and Financial Structure Database), except the capital account openness index, which is sourced from Chinn and Ito (2006).

**Table 2**
Model with Full Controls

| | (1) | (2) |
|---|---|---|
| Dependent variable: green policy | | |
| Vulnerability | 0.903*** (0.333) | |
| Sensitivity | | 0.785*** (0.180) |
| Readiness | −0.100 (0.0923) | −0.0614 (0.0904) |
| Real GDP (US$) | 0.267*** (0.0740) | 0.266*** (0.0707) |
| CPI | 0.367*** (0.0658) | 0.416*** (0.0653) |
| Real GDP per capita | −0.702*** (0.220) | −0.680*** (0.213) |
| Private-sector credit | 0.0764* (0.0407) | 0.0589 (0.0394) |
| Int'l reserves (% of GDP) | −0.100*** (0.0357) | −0.0943*** (0.0349) |
| Bank deposits (% of GDP) | −0.158** (0.0635) | −0.105 (0.0638) |
| Central bank assets (% of GDP) | −0.0545*** (0.0198) | −0.0654*** (0.0194) |
| Capital a/c openness | −0.334*** (0.105) | −0.342*** (0.101) |
| Constant | 0.109 (0.145) | −0.105 (0.124) |
| Observations | 292 | 292 |
| $R^2$ | 0.689 | 0.703 |
| Country FE | Yes | Yes |
| Time FE | Yes | Yes |
| No. of countries | 17 | 17 |

All year fixed effects are omitted from reporting. Standard errors are in parentheses.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

with our baseline estimates. This further highlights the robustness of our initial finding—that vulnerability to climate change is a strong driver of a country's imposition of green financial policies. Furthermore, the magnitude of the vulnerability and sensitivity coefficients has decreased somewhat from 3.5 to 0.9 standard deviations for vulnerability and from 1.4 to 0.79 for sensitivity, implying that some of the explanatory power attributed to climate risks in the baseline regression has now been absorbed by the economic and financial determinants of green financial policies. However, the main relationship of interest remains economically and statistically significant, emphasizing its robustness.

Of the controls, the economic size of a country as measured by its real GDP plays a significant positive role in determining the intensity of green financial policies in case of both vulnerability and sensitivity to climate risks. This

implies that larger countries are more likely to undertake green financial policies, contrary to the prior noted earlier.[21] On the other hand, the level of economic development proxied by real GDP per capita has a significant but negative coefficient, implying that more economically developed countries are less likely to experiment with green financial policies. This is consistent with our expectations around credit guidance policies being adopted more by less developed economies. We also see that countries with higher inflation are likely to use financial policies to manage inflation risks, including those arising due to climate-related factors. Since higher inflation levels are less likely to be associated with central banks entrusted with a narrow inflation-targeting mandate, central banks in countries with broader mandates are more likely to be associated with a higher intensity of green financial policies.[22]

Among the external variables, international reserves to GDP and capital account openness are consistently negative and statistically significant across both models. A higher level of international reserves signifies a lower susceptibility to the adverse effects of external-sector shocks, including those arising from the cross-border effects of climate risks, reducing the need to resort to green financial policies. This is in line with our initial hypothesis. Greater capital account openness is also associated with lower use of green financial policies. This may be reflective of the fact that more financially open economies tend to use financial and regulatory policies less aggressively, as they are concerned about the impact they may have on capital flows.

With regard to the financial variables, we consider central bank assets (as a proportion of GDP) as a proxy for central banks' financial independence, the hypothesis being that larger central bank asset sizes are more likely to be correlated with higher levels of CBI (Ivanovic 2014). The negative coefficient on this variable in our extended model confirms our hypothesis that larger central banks are correlated with a lower green financial policy intensity, ceteris paribus. On the other hand, smaller central banks (most likely those in developing economies) are less independent and thus complement government efforts and fiscal policies with green financial policies to mitigate climate risks. Insofar as larger central bank assets relative to GDP also indicate a more financially developed economy, our results suggest that a higher level of financial development reduces green financial policy intensity. This suggests a higher risk-absorbing ability (including of climate risks) of more financially developed markets, thereby reducing the need for imposition of green financial policies. This effect outweighs an opposing effect, namely, the relative ease with which green financial policies can be implemented in more financially developed economies given the existence of an already established deep financial market.

21. One possible reason for this could be that bigger countries are likely to rely on specialized centralized institutions (such as central banks) for creating policies.
22. Overall results remain unchanged if we use other proxies for institutional capacity or if we remove it from the regressions altogether.

## Conclusions

Central banks are increasingly acknowledging the impact of climate-related physical and transition risks on their mandates and are considering the feasibility of using various policy tools to mitigate against such risks.

Through the regulatory learning that has occurred until now, financial and supervisory policy tools have emerged as an important response to mitigate the financial risks arising from climate change and extreme weather–related events (Network for Greening the Financial System 2020). In this context, this article is a first attempt to analyze the determinants of such policies' imposition. In this article, we examine the association between climate risks and green financial policies. The empirical findings confirm our hypothesis of a higher vulnerability to climatic risks being a significant predictor of greater green financial policies' uptake by central banks in a nonrandom sample of countries. Other secondary factors that matter include a country's economic size, level of financial development, extent of CBI, and external-sector vulnerability.

Future research could build on our findings in several ways to further analyze central banks' role in mitigating climate change as well as the effectiveness of their policies. One particularly promising area of future research is examining the channels and mechanisms that connect climate risks with central bank action in this sphere.

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