e-axes FORUM

Climate Risks in Financial Markets

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Executive summary

Climate change has a destabilizing effect on financial markets that are subject to both physical risks and transition risks. If market actors fail to assess these risks, the financial sector will become increasingly overexposed to climate sensitive assets and vulnerable to climate shocks. The ensuing market failure provides the justification for central bank intervention in order to prevent cascading and adverse financial effects.

This is a brief based on a series of webinars we organized from February 14, 2022 to March 14, 2022.

"Climate Finance"
Stefano Giglio, Yale School of Management.
Based on his November 2021 paper, published on the Annual Review of Financial Economics

"Achievements and Challenges in the ESG Markets"
Michela Scatigna, Bank for International Settlements, and **Omar Zulaica**, Bank for International Settlements.
Based on the December 2021 paper they co-authored with Dora Xia and Anna Zabai, published on the BIS Quarterly Review

"Achievements and Challenges in the ESG Markets"
Irene Monasterolo, EDHEC Business School, **Sujit Kapadia**, European Central Bank, and **William Oman**, International Monetary Fund.
High-level panel discussion

1 Problem

According to Mark Carney, former Governor of the Bank of England, climate change exposes financial markets to two different risks: physical and transition risks.[1] Physical risks reflect the costs of more severe and more frequent natural disasters (e.g. floods, droughts and hurricanes) as well as permanent changes in weather conditions (e.g. hotter temperatures and rising sea levels). These events may i) directly damage firms by disrupting physical assets, like a hurricane that destructs a manufacturing plant; ii) indirectly hit firms' supply chain, like a flood that runs off a transport infrastructure. For example, exposure to extreme temperatures can adversely affect corporate earnings (Addoum et al., 2019), revenues and operating income (Pankratz et al., 2019) and derivative prices (Kruttli et al., 2019).

Transition risks stem from the economic and financial transformations required to shift to a low-carbon economy. These processes may i) directly affect firms through the imposition of a carbon tax or a change in environmental policy; ii) indirectly impair their financial position, through the deterioration of their financial position due to the ownership of stranded assets. The materialization of these risks may hurt firms' cash flow, erode the value of their assets, and impact their creditworthiness and capitalization. For instance, after the signature of the Paris Agreement, credit ratings and yields changed for polluting firms (Seltzer et al., 2020).

Ultimately, if markets fail to efficiently assess climate risks, the ensuing asset mispricing would hinder the ability of investors to adjust their portfolios according to their preferred risk-return profile and would jeopardize the regulatory efforts of policymakers. As a result, in response the realization of an extreme natural event, the whole economic system could be affected through cascading effects[2].

1.1 Assessing climate risks

Even though the literature addressing the financial impact of climate change is still relatively recent, some attempts to measure the related financial costs have already been made by policy makers, academia and the private sector. On the policy side, several central banks and governmental institutions have compiled internal reports assessing the exposure of the national banks and insurers to climate risks (Regelink et al., 2017; Bank of England, 2018, 2022; Banque de France, 2021)[3]. On the academic side, the approaches to quantify climate-related financial risk include integrated assessment modelling (IAM)[4],

[1] He also mentions a third source of risk: the liability risk. It refers to the case in which some economic actors, after suffering damage induced by climate change, will seek compensation from those who they believe to be responsible for it. Carney, M (2015), "Breaking the tragedy of the horizon – climate change and financial stability", speech at Lloyd's of London, London, September 29th 2015.

[2] For example, a sudden drop in asset values may hamper the ability of a bank to obtain liquidity in the interbank market and may shrink the value of collaterals available to firms and households to support credit demand. For reference on cascading effects, see (Dietz et al., 2016; Hildén et al., 2020; Carter et al., 2021; King, 2022)

[3] Other institutional entities that developed some assessing method (or guideline) for climate-related financial risks are (European Central Bank, 2022), (Behnam et al., 2020). For a review, see (Rudebusch, 2019)

[4] Simply put, IAMs are dynamic theoretical models that simulate economy-climate interactions through a damage function, that quantify the impact of climate change on economic output. By far, the most utilized IAM is the DICE model (Nordhaus, 2017). IAMs are often criticized for their use of arbitrary functional forms, that do not take in account the "double layer of uncertainty" that surrounds climate modelling. In fact, the impossibility to realistically estimate the climate sensitivity (degree of change in temperature caused by an increase in carbon emissions) and the complexity of the feedback loops between the economic system and the environment makes the representation of the interaction between the economy and the environment seemingly impossible to achieve (Pindyck, 2017)

macro-empirical estimates[5], structural models with multi-layered uncertainty[6] and agent-based models[7]. The private sector too developed methods to identify climate exposure of assets and firms. For investors, by far, the most adopted firm-level measure of such climate related risk, is based on the ESG framework[8], even though recently the reliability of these ratings has been seriously questioned[9]. Despite all the work that has been done in recent years by virtually every economic actor, climate risk remains hard to quantify. For instance, Hong et al. (2019) find that international food stocks are under-reacting to heightened drought risks and Kumar et al. (2019) argue that the stocks of firms with higher climate sensitivity are generally mispriced in certain segments of the market. Thus, we shall ask: **how can we reliably assess climate-related risk in financial markets?**

1.2 Mitigating climate risk: financial regulation

The inability to properly quantify climate risk may hamper the monetary policy transmission mechanism (Network for Greening the Financial System, 2020). On one hand, contractionary policy may be hindered due to the reduced creditworthiness of firms exposed to climate change, that, following a rise in interest rates by the central bank, may spur a rise in non-performing loans (NPLs) on the lenders' balance sheets. On the other hand, expansionary monetary policy may struggle to stimulate demand, due to a reduced interest rate sensitivity of investments and savings, sparked by a greater risk aversion from firms (that would halt investments) and households (that would increase precautionary savings). Both the rise of NPLs and the reduced investments can eventually shatter production and undermine employment, with inevitable effects on prices (see Figure 1)[10]. For this reason, climate change mispricing is a market failure that central banks must fix. One of the main sources of bias is the low awareness companies have of their exposure to climate risks (Campiglio et al., 2018) which inadvertently leads to investors constructing portfolios with imperfect information on the exposure to climate-related risks. Lenders and insurance underwriters should know if the business model of a company is particularly sensitive to climate change, and investors should be made aware of the impact of climate change on their portfolios. For this reason, the push towards enhanced climate-related financial disclosure has recently gained traction[11]. However, the widespread adoption of climate disclosure has been constrained by lack of comparability between standards (Monasterolo et al., 2017), ambiguous effects on stock returns (Bolton et al., 2020) and investors' professional biases towards short-term profits (Campiglio et al., 2018).

[5] Currently available data do not reflect the real probability of occurrence of future climate shocks, which are characterized by deep uncertainty (Chenet et al., 2021) and non-linearities (Bolton et al., 2020). Also, they do not account for threshold effects, which are salient in understanding climate outcomes. In fact, (Weitzman, 2007) argues that the distribution of the expected impact of climate change-induced natural events on the economy has thick tails, meaning that the devastating effects of the rarest events cannot be deemed negligible just on the base of standard probability assumptions.

[6] See (Wagner & Weitzman, 2018; Barnett et al., 2020)

[7] Agent based models (ABMs), just like Stock-Flow Consistent (SFC) models, are better suited to study economy-climate interactions due to the incorporation of heterogenous agents, uncertainty in decision-making process, network effects, non-linearities and disequilibrium phenomena ((Campiglio et al., 2022)). For a review of complex system models applied to climate change, see Balint et al. (2017). Recent attempt to apply ABMs to climate change are Lamperti et al. (2018, 2021). Viceversa, Dafermos et al. (2017); Monasterolo & Raberto (2018); Bovari et al. (2018) are examples of SFC models.

[8] See Fink (2022)

[9] ESG ratings change significantly overtime Berg et al. (2021) and widely diverge from a rater to another (Berg et al., 2022). In general, corporate' sustainability performance does not appear to be correlated with stock returns (Berchicci & King, 2022)

[10] For a detailed discussion of the challenges that climate change poses to monetary policy transmission, see Drudi et al. (2021)

[11] Some existing reporting frameworks are the Task Force on Climate-Related Financial Disclosure (TCFD) and the International Financial Reporting Standards (IFRS) while other legal frameworks are the Non-Financial Reporting Directive of the European Union and the French Energy Transition law.

A tool policymakers can use to mitigate climate-related financial risk is prudential regulation (D'Orazio & Popoyan, 2019)[12]. For example, regulators could increase the capital adequacy requirements (CARs) to discourage lending to carbon intensive activities (Monnin, 2018), reduce their reserve requirements according to the amount of lending flowing to green investments (Volz, 2017) [13], and adjust haircuts based on the environmental impacts of the assets (Dafermos et al., 2021)[14]. These lender-based instruments[15] are aimed at supporting the low-carbon transition by easing credit to green activities, however they could jeopardize financial stability and be easily by-passed by firms that raise funds in international financial markets (Campiglio et al., 2018). **What can the central bank do to mitigate climate change while maintaining financial stability?**

Financial stability is inherently linked to the agents' need to price in climate risk in their transactions and to their ability to hedge their positions against it. In his comprehensive review, Dennis (2022) surveys the literature on the effects of climate change on different asset classes. Some climate shocks severely hit asset prices across the board, causing steep mean-reverting corrections with long persistence[16]. For example, house prices in flooded areas take years to recover (Atreya et al., 2013; Chandra-Putra & Andrews, 2020) just like fund managers' stock valuations (Kumar et al., 2019) or firms' perceived creditworthiness (Correa et al., 2022). Other climate shocks, although still unrealized, are nevertheless anticipated by market participants with different effects on prices depending on market segmentation, belief heterogeneity and policy salience (Giglio et al., 2021)[17].

According to Giglio et al. (2021), another factor that influences the direction of the effect on asset prices and risk premia is the source of uncertainty associated with climate change. There are two main possible sources of uncertainty: the future evolution of climate and the future path of economic activity[18]. In the scenario in which uncertainty emanates from the climate process, the shock can be interpreted as the realization of a natural disaster which damages present economic activity and reduces future expectations of consumption. In this case, assets with low payoffs when climate risk is high tend to require positive risk premia (if the shock is persistent, the longer the horizon the higher the premium); on the contrary, assets that payoff primarily when climate risk is realized, like mitigation investments, will have negative risk premia (if the shock is persistent, the longer the horizon the lower the premium) and will provide a hedging opportunity to investors. In the scenario in which uncertainty arises from the future path of the economy, climate damages are higher when consumption is already high. This means that mitigation investments will have a low marginal utility and will be regarded as relatively risky investment, requiring positive risk premia. To sum up, climate change is a risk factor whose effects on prices and premia are ambiguous, so **how can investors mitigate the risks that climate change poses to their portfolios?**

In this policy brief, we discuss how the three questions above can be answered i) how

[12]See also European Systemic Risk Board (2022)

[13]Bank du Liban implemented this measure in 2010

[14]In 2018, People's Bank of China decided to include green bonds in the pool of eligible assets that banks can use as collateral for borrowing through the central bank's medium-term lending facility (Macaire & Naef, 2021). Also, the ECB has announced that it will restrict the share of assets with a high carbon footprint that can be pledged as collateral (E. C. Bank, 2022)

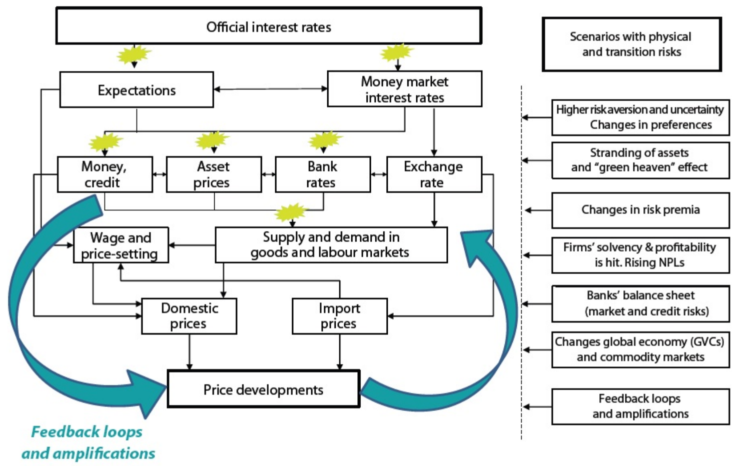
[15]See D'Orazio & Popoyan (2019) for a review.

[16]Dennis (2022) refers to the risk to which agents are exposed in this case as "acute physical risk". Interestingly, he argues that the market's psychological tendency to revert back to the original price may not be the normal consequence of an overreaction to the shock, but may stem from the agents' wrong belief that physical variables will return to "normal" after the shock. In the case of climate change, some natural conditions are non-stationary and assuming the contrary may cause "bubble-like divergence between the (climate-) fundamental value" of the asset.

[17]These "chronic physical risks" particularly influence the real estate market (i.e. flood risk on home values in coastal areas) and the equity markets (i.e. carbon emissions risks on highly polluting firms).

[18]They cite also a third one: uncertainty about the various component of the climate-economy model that estimates the effects. We do not explore this further hypothesis because it goes beyond the scope of the brief.

Figure 1: The monetary transmission mechanism in a climate change regime



Source: Network for Greening the Financial System (2020)

financial markets are pricing climate risk; ii) what is the role of central banks in mitigating climate-related financial risk and iii) what can investors do to hedge against these risks. First, a paper by Scatigna et al. (2021) sheds light on the existence of a carbon premium in firms funding costs, that signals a market preference towards cleaner firms and provides an example of how investors assess climate risk in the bond market. Secondly, we refer to the work by Battiston et al. (2017), who developed a network-based climate stress-test to understand the system consequences of investor's overexposure to brown assets. Lastly, Giglio et al. (2021) review the literature on how different asset markets, including equities and real estate, price in and hedge themselves against climate risks. Even though climate finance is a nascent field, these studies perfectly summarize the mechanisms through which market agents allocate their resources in a climate change regime and the criticalities that may arise if those allocations are misaligned with respect to climate-fundamentals.

2 Theory and Empirical Evidence

2.1 Assessing climate risks

According to Schoenmaker & Tilburg (2016), financial firms that integrate ESG criteria in their investment strategies to address climate risks basically have two options: divestment or engagement. The first option requires a limit to the share of capital exposed to climate risks on the firm's total equity. The second option implies a more active involvement in the low-carbon transition which entails both divesting from "dirty" activities and actively financing "green" investments. Krueger et al. (2019) surveyed institutional investors on their climate risks perceptions and found that engagement rather than divestment is the most preferred strategy to address climate risks. Strong engagement in ESG investment, translates in a demand-driven upward pressure on "green" asset prices, which eventually increase investors' risk-adjusted returns (Brandon, Krueger, & Mitali, 2021).

In line with this hypothesis, Scatigna et al. (2021) find some evidence that **energy intensive firms are perceived as riskier than their "greener" counterparts**. They study the impact of a firm's E-score[19](E from ESG i.e. the environmental score) on its secondary market bond yield in Europe and in the U.S. and define two different channels through which market participants assess the firms' climate risk: the risk channel and the preference channel. Through the risk channel, market participants associate the information about the firm's environmental performance with its creditworthiness. Through the preference channel, investors committed to the low-carbon transition express their predilection towards clean assets. It emerges that, for U.S. firms (considering both the overall sample and the energy-intensive subsample), the preference channel is statistically and quantitatively more robust than the risk channel. In fact, following a 10% increase in the firms' E-score, the option-adjusted spreads for the overall U.S. sample increase by 2 basis points (6 basis points for the energy-intensive subsample), while the default probability ratio increases only by 0.4 basis points (0.3 for the energy-intensive subsample)[20]. The results demonstrate that engagement has stronger financial benefits than divestment.

This work relies upon the assumption that ESG ratings are a robust signal of compliance to environmental criteria (West & Polychronopoulos, 2020). However , ESG reliability as a market signal remains a controversial issue. (Berg et al., 2021) calculate that the correlation between the scores established by six ESG raters ranges from 0.38 and 0.71 and argue that the divergence is driven by: a) the fact that ratings are based on different attributes; b) raters use different indicators to measure the same attribute; and c)raters take different stance on the importance of some weights[21]. Christensen et al. (2022) find that encouraging ESG disclosure, rather than fixing the divergence, increases disagreement and (Brandon, Krueger, & Schmidt, 2021) find that ESG disagreement (not market preference towards green assets) is positively correlated with asset performance .

Overall, Scatigna et al (2021) expand the literature on the financial effects of ESG engagement[22], by adding both ESG risk and performance to the discourse[23]. The positive correlation between ESG and performance and the negative relation between ESG and risk can be explained by the fact that investors' preference towards high ESG performance firms tilts their holdings towards "green" companies, decreasing their expected returns and therefore their cost of capital (Berg et al., 2022). Despite the existence of these financial benefits, there is still little evidence of real economic benefits of ESG engagement, mostly focused on corporate social responsibility and real investments (Broccardo et al., 2022; Oehmke & Opp, 2019; Ľuboš Pástor et al., 2022).

[19]Proxied by Scope 1 carbon emissions.

[20]For European firms the picture is mixed. For the whole sample, the risk channel is slightly stronger than the preference channel (0.8 bp increase vs 0.7); for the energy-intensive subsample, the risk channel is statistically significant (0.5 bp increase) while the preference channel is statistically non-significant (1 bp increase).

[21]They also find a rater effect, which captures the fact that a firm with an high score in one category, automatically scores high in the others.

[22]For further research on the value-enhancing effect of ESG on assets see Flammer (2021) on corporate green bonds and **?** for equities.

[23]Bolton & Kacperczyk (2021) estimate that one standard deviation increase in emissions leads to a rise in expected return of 2%, consistent with the investors' demand for higher compensation for their exposure to carbon risk. Ilhan et al. (2021) show that the cost of option protection against extreme downside risks is larger for firms with more carbon-intense business models, and particularly so at times when there is an increased public attention to climate risk. Conversely, Hoepner et al. (2022) show that ESG engagement alleviates the firm's exposure to downside risk factors.

2.2 Mitigating climate risks

2.2.1 Financial regulation

Considering the negative externalities deriving from climate change-related risks, regulatory authorities should step in with the aim of aligning financial stability and climate change mitigation. In particular, central banks are the institutions responsible for guaranteeing the stability of the financial system as a whole, more so after the introduction of the Basel III Accord, which was developed in the wake of the Great Financial Crisis (2007-2008) to shield the economy from systemic financial risks. The Basel III framework represents the state of the art in macroprudential regulation and consists of three Pillars: a) enhanced minimum capital requirements and liquidity requirements; b) enhanced supervisory review and enhanced risk disclosure and c) market discipline. However, none of them explicitly targets climate mitigation (D'Orazio & Popoyan, 2019) and any proposal linked to the use of monetary policy in climate change mitigation has triggered strong reactions (Volz, 2017; Dafermos et al., 2021; Campiglio et al., 2018). Nonetheless, the role of central banks in developing supervisory policies has been uniformly accepted.
climate-related prudential risks should be incorporated into regular stress test exercises and European Systemic Risk Board (2016).

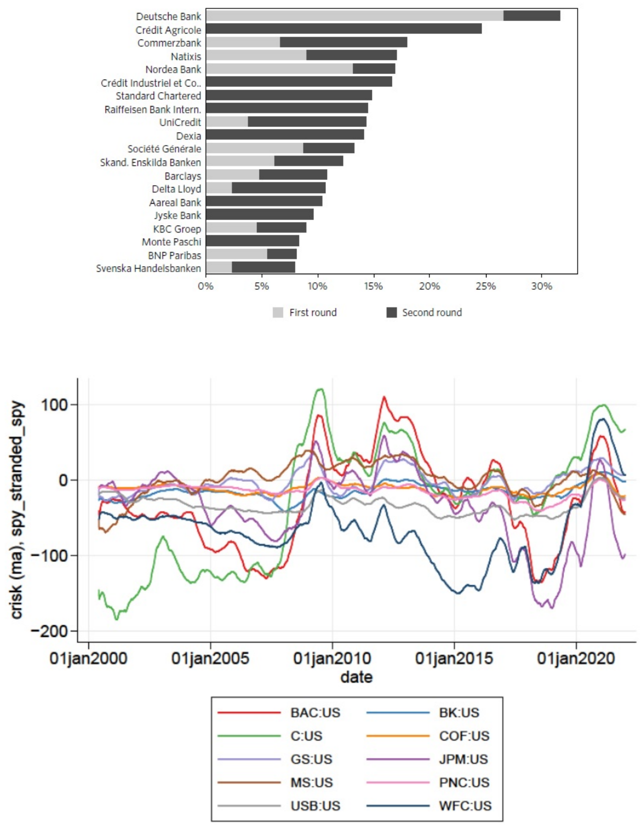
In general, a climate-related stress test (CRST) assesses the resilience of both individual actors and the financial system as a whole to hypothetical adverse climate shocks. CRST involves scenario analysis techniques, aimed at quantifying the impact of extreme/rare/adverse climate shocks on a number of financial parameters, such as liquidity, capital adequacy ratio, valuation (Chenet et al., 2015). They can be implemented either with a macro-prudential or with a micro-produntial perspective (Chenet et al., 2021). While macroprudential stress tests estimate the impact of an adverse shock on the financial system as a whole (Anderson et al., 2018)[24], microprudential stress tests evaluate the fragility of the balance sheet of individual financial entities.

A great example of a novel macro-CRST methodology is provided by Battiston et al. (2017). The paper develops a static network-based climate stress-test applied to large euro area banks under four different shock scenarios. Firstly, they quantify the firms' direct exposure to climate risk by calculating the monetary value of the assets owned by the firm. Secondly, they assess the firms' indirect exposure measuring the monetary values of its supply chain counterparties' assets. Then, they reclassify the assets according to a novel classification of Climate Policy Relevant Sectors (CPRS). This classification allows the authors to understand the climate exposure of investors in terms of the portfolio's sectoral composition. They run the stress test by: i) first applying a progressively aggregated shock to two climate-sensitive sectors and calculate the investors' equity loss (see Figure 2a); ii) and second, by applying four shock scenarios to different climate-sensitive sectors and calculate the investors' VAR. For example, a 100% shock to the market capitalization of the "fossil-fuel" and the "utilities" sectors generates a 13.2% (direct effect) equity loss for EU banks (that goes up to 27.9% once indirect effects are included). They conclude that **network-based CRST methodology allows to identify individual financial risks and their propagation through the financial system.**

On the microprudential side, Jung et al. (2022) develop a dynamic CRST methodology, calculating the exposure to climate risk of large private banks in the U.S, U.K, Canada, France and Japan between 2000 and 2021. They use the return of a bank's "stranded assets"

[24] Examples of macroprudential CRSTs run by central banks are: Vermeulen et al. (2018); S. A. R. Bank (2021); Banque de France (2021); Bank of England (2022); of Canada (2022); European Central Bank (2022)

Figure 2: Climate Related Stress Test Results



Notes: Figure 3a (up) shows the First- and second-round losses in banks' equity for the 20 most-severely aected EU listed banks, under one of the four climate shock scenario in Battiston et al. (2017); Figure 3b (down), shows the equity losses of the biggest 10 U.S. banks following the capital shock constructed by Jung et al. (2022).
Source: Battiston et al. (2017);Jung et al. (2022)

(i.e. fossil fuel producers) portfolio as a proxy for climate risk[25] and estimate the bank's portfolio return sensitivity to both climate risk (namely, climate beta) and normal market risk (market beta). The authors then calculate the expected capital shortfall, which is a positive function of the climate beta, conditional upon the bank's size and leverage. Finally, they construct an extreme shock, represented by a 50% fall in the "stranded assets" portfolio return. They find that expected capital shortfall is aligned with the bank's exposure towards the fossil fuel sector. Also, after disentangling the climate stress from the market stress, they find a sizeable deterioration in the banks' equity across countries after the shock (see Figure 2b) and a subsequent increase in the probability of default for "brown" banks.

CRST methodologies are crucial tools for regulators to assess the systemic financial risk associated with climate change. Using different settings (static or dynamic, macro-based or micro-based) and different proxies for climate risk factors (owned equity assets or syndicated loans), regulators can quantify the value at risk on asset losses (Battiston et al., 2017), the expected capital shortfalls and the changes in default probabilities (Jung et al., 2022) of large financial operators.

[25] As opposed to other market-based measures like the climate news index Engle et al. (2020) and the asset value of their whole portfolio Battiston et al. (2017)

2.2.2 Financial markets

A crucial function of financial markets is to enable risk sharing. In a climate change scenario, financial markets should: a) assess physical and transition risks by engaging in sustainable activities and divesting from carbon-intensive ones; and b) try to mitigate those risks through hedging strategies. In their review article, (Giglio et al., 2021) argue that " understanding the empirical relationship between climate change and asset prices has the benefit of giving us implementable indications on how to use financial markets to hedge climate risks". The problem is that both the effects of climate change and the time horizon in which they will materialize are subject to unpredictability. Moreover, the authors also warn that the stream of information regarding the economic response to climate shocks will add a layer of uncertainty.

One example of a portfolio hedging strategy which could mitigate long-term economic damages of climate change has been proposed by Engle et al. (2020), who combine traditional dynamic hedging with textual analysis. They construct a "climate news" index, using *The Wall Street Journal* (WSJ)'s article texts to measure the climate change coverage in the media and other publications. The idea is that, when extreme natural events occur or other environmental disasters happen, the media and the newspapers increase their coverage[26]. Then, the authors propose to build a dynamic hedge portfolio which systematically overweights stocks with low climate risk exposure and underweights stocks with high climate risk exposure[27]. The portfolio is built following a mimicking-regression approach to isolate climate change risk. It includes E-Score-sorted U.S. equities and a set of well diversified projection portfolios that include three other risk factors that may be correlated with cross section returns (cross-sectionally standardized market value, values of book-to-market, share of total market value). The underlying assumption is that the risk exposure of assets used to estimate the portfolio remains constant over time.

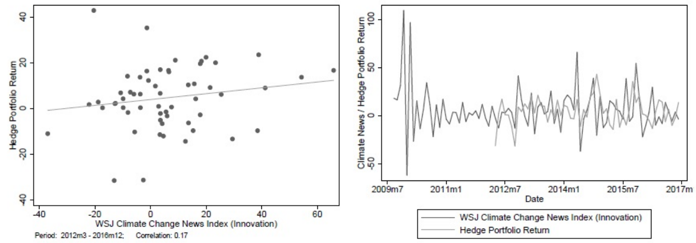
The mimicking portfolio is used to hedge against the climate news index. In-sample results show that, **in a period with more negative news on climate, a portfolio built on E-Scores that goes long on "green" stocks has relatively larger excess returns**[28]. The paper includes also a test of the portfolio's ability to hedge for out-of-sample climate news (news that were published in months that were not included in the estimation of weights). For this purpose, they estimate the weights of the hedging portfolio using the data from the first month of their sampling period (t_{min}) to the month before the hedging time ($t-1$). Then, they calculate the correlation between the returns of that portfolio and the climate news index in t. With this strategy, they effectively simulate real time hedging. They find evidence of positive out-of-sample correlation between the climate news index and the hedging portfolio, meaning that the portfolio provides a good hedging strategy (see

[26]The implicit assumption is that climate news is bad news and no news is good news. To fix this issue, the authors build another news index, specifically structured to account only for bad news, drawing from the Crimson Hexagon (CH) collection. CH has a corpus of more than a trillion news and articles from more than 1,000 sources. The strength of the CH collection is that each article is categorized to have "positive sentiment" or "negative sentiment" and is provided by further sub-categories (joy, fear etc.) The authors consider all the articles about "climate change" classified as being of "negative sentiment".

[27]Climate risk exposure is proxied for each firm by the E-Score extrapolated by two ESG rating providers: MSCI and Sustainalytics. In particular, the E-Score deriving from MSCI data is calculated by assigning a negative value to all the negative environmental sub-categories and a positive value to all the positive ones. An high E-Score suggest that the firm is environmentally friendly. Sustainalytics ratings come already disaggregated by category ("Total Environmental Score", "Total Social Score" and "Total Governance Score"), so they directly use the "Total Environmental Score". They document that, of all the 796 firms that have both scores, the correlation between the two scores is 0.65.

[28]Of two "green" portfolios, one built with Sustainalytics and one with MSCI, the Sustainalytics-based one appears to be a better hedge, covering 15-18% (depending on the E-Score sorting mechanism) of the in-sample variation of the WSJ climate news index (vs 8%) and 12%-13% of the in-sample variation of the CH index (vs 9%). Also, it appears that bigger firms in terms of size are more exposed than smaller ones to bad climate news.

Figure 3: out-of-sample performance of hedge portfolios



Notes: On the left-hand side, the graph shows the linear correlation between the WSJ climate news index and the hedge portfolio returns (0.17). On the right-hand side, the chart shows how closely the hedge portfolio tracks the climate news index on the sampled period.
Source: Engle et al. (2020)

Figure 3)[29].

Engle et al. (2020) argue that mimicking portofolios, similar to the one described above, points also to a useful way to infer risk premia. In fact, the expected excess return of the mimicking portfolio is equal to the risk premium of the underlying non-tradeable risk (i.e. climate change). If we assume that the climate risk premium is positive (Scatigna et al., 2021), then the mimicking portfolio should have a negative risk premium (Giglio et al., 2021). Nonetheless, the researchers identify a caveat: if the timespan considered to build the mimicking portfolio is particularly dominated by bad climate news, the mimicking portfolio would then lead to a wrong estimate of the climate premium.

3 Policy Recommendations

Classic public policy theory identifies three major functions for economic policymakers: the *allocation* of resources, the *redistribution* of wealth and the *stabilization* of the markets[30]. Traditionally, the allocative and redistributive functions are carried out by elected authorities with a fiscal mandate (governments), while stabilization and monitoring are prerogatives of un-elected agents with a monetary mandate (central banks). However, this framework becomes blurred and ill-suited to address climate change-related shocks. In fact, while it is true that central banks should focus on aggregate macroeconomic variables, such as prices and employment, it is also true that climate change may put price stability in peril. Also, the timing mismatch between short-term focused monetary policies and long-term impacts of climate change is in contrast with the already evident financial disruptions triggered by current climate shocks (Brunnermeier & Landau, 2022). This controversy fuels a long-standing debate on whether a central bank should deploy its wide array of specialized policy tools to tackle climate change and defend financial stability.

Supporters of an active involvement of central banks in the low-carbon transition argue that climate-related stress tests "are a very important first step to calibrate and evaluate green macroprudential tools" (D'Orazio & Popoyan, 2019). However, CRSTs heavily rely on good

[29] Out-of-sample correlation between the WSJ climate news index and the Sustainalytics-based portfolio is clear and positive and equals to 0.17. The MSCI-based portfolio has 0.01 out-of-sample correlation with the WSJ climate news index, meaning that the portfolio does not provide a good hedging strategy.

[30] see Musgrave (1959)

quality data and the current lack of consensus regarding how to disclose information is a major obstacle. According to Irene Monasterolo, Professor of Climate Finance at EDHEC Business School, financial regulators should enforce an enhanced disclosure in order to ensure a correct climate risk pricing[31]. In particular, Monasterolo suggests that a better measure of how the firm is hedging its transition risk is given by its energy technology profile, rather than its emission trajectory. Looking at the firm's energy technology data, such as how much CAPEX and OPEX is being allocated towards an energy strategy, has two advantages: i) it may help clean up some noise in carbon disclosure (i.e. greenwashing); ii) it captures a forward-looking dimension that is often neglected by models based on past data. On the other hand, data on physical risks are more challenging to collect and such risk is hardly hedgeable, nevertheless a good starting point might be to collect plant-level information.

At the theoretical level, CRSTs can be seen as part of the stabilization tools of monetary authorities and appear to be in line with the mandates of central banks. Conversely, other green policies like "green" asset purchase programs (Matikainen et al., 2017; Monnin, 2018; Campiglio et al., 2018), "green" collaterals (Dafermos et al. 2021) and other prudential policies (D'Orazio & Popoyan, 2019)[32] are criticized for producing spillovers in allocative and redistributive terms (Brunnermeier & Landau, 2022). In particular, William Oman, Economist at the International Monetary Fund, thinks that central banks' regulation is a poor substitute for the intervention of fiscal authorities. He adds that large asset purchases programs might imperil central banks' market neutrality[33], imply strong carbon biases[34] and encourage collective moral hazards that would exacerbate mispricing of climate risks. Sujit Kapadia, Head of Market-Based Finance of the ECB's Directorate General for Macroprudential Policy and Financial Stability, is also in agreement and argues that a carbon tax "has got to be the main part of the solution". He also adds that the private sector, represented by banks and insurers, should step in, steering their investment portfolios towards Paris-compatible targets and filling the insurance protection gap[35].

For some scholars though, central bank market neutrality "would entail ignoring the existence of a market failure when asset prices do not incorporate the costs of global warming" (Brunnermeier & Landau, 2022). Moreover, it is not clear if delegating to the private sector (i.e. the asset management industry) the power to shape future climate policy would prove more effective than public interventions (Gabor, 2021). In fact, limiting the role of the central bank to an informational (through transparency and disclosure) and market-incentive role (by de-risking green assets), has so far led to little improvements in capital reallocation from carbon-intensive investments to cleaner ones (Kedward et al., 2022). For this reason, supporters of a "green" public sector argue that institutions should leverage their market shaping capacity to accelerate the green transition (Mazzucato & Ryan-Collins, 2022) and embrace a promotional role in support of a green industrial policy.

[31]See "Policy panel: "Climate risks in financial markets", E-axes Forum Webinar Series, 14th of March 2022. Link: https://www.youtube.com/watch?v=zquM_rK0ySY.

[32]Lamperti et al. (2021) employ a macro-financial agent-based model to assess the effects three different "green" macro-prudential policies: "green" capital requirements, green public guarantees to credit and carbon risk-adjustment to credit ratings. They find that some combinations of policies fuel credit booms, exacerbating financial instability and increasing public debt, while the combination of all three instruments leads to a virtuous cycle of (mild) emission reductions, stable financial sector and high economic growth.

[33]See Campiglio et al. (2018)

[34]See Matikainen et al. (2017)

[35]See for example Tesselaar et al. (2022), who calculate the extent of charity hazard and the flood insurance protection gap for EU-countries until 2050.

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