Climate risks and financial stability

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Abstract

Climate change has been recently recognised as a new source of risk for the financial system. Several financial supervisors with a financial stability mandate have recently recommended that investors and financial institutions need to assess their exposure to climate-related financial risks and conduct climate stress-tests. Nevertheless, they fall short of methodologies to do so. Indeed, the characteristics of climate risks (like deep uncertainty, non-linearities and endogeneity) challenge traditional approaches to macroeconomic and financial risk analysis. Embedding climate change in macroeconomic and financial analysis is fundamental for a comprehensive understanding of risks and opportunities in the era of the climate crisis. This Special Issue is devoted to the relations between climate risks and financial stability and represents the first comprehensive attempt to fill methodological gaps in this area and to shed light on the financial implications of climate change. It includes original contributions that use a range of methodologies, like network modelling, dynamic evolutionary macroeconomic modelling and financial econometrics, to analyse the impacts of climate-related financial risks, as well as of financial policies and instruments aiming at the low-carbon transition. The research insights of these contributions inform financial supervisors about the integration of climate change considerations in financial risk assessment.

Keywords: climate change, financial stability, climate policies, financial instruments, network models, stock-flow consistent models, agent based models, empirical finance.

1. Why a special issue on climate risks and financial stability?

While climate change has been increasingly recognised as a major source of risk for the financial system, and the academic and policy community has started paying growing attention climate finance, there is still a significant gap in the development of methodologies that allow us to analyse successfully climate-related financial risks. The aim of this Special Issue of the *Journal of Financial Stability* (JFS) is to address this gap. To our knowledge, this is the first Special Issue devoted to the relation between climate risks and financial stability. This relation has significant implications for the transition to a low-carbon economy and raises significant methodological issues for the academic community. Climate risks' specific characteristics (such as endogeneity, non-linearities and deep uncertainty) pose fundamental challenges to traditional methods for macroeconomic and financial analysis, which are not well-suited to capturing these characteristics. Progress in this field requires that scholars engage with the fundamental questions raised by climate risks and avoid rebranding existing models under the label of 'climate change'.

Climate change implies new sources of financial risk already now and in the coming decades. The reason is straightforward and follows from the knowledge on climate change that has been developed in the last two decades (IPCC 2014, 2018). In the absence of a sufficient mitigation action, climate

change implies an increasing potential for adverse socio-economic impacts because of extreme weather events and other types of hazards, across several economic activities and geographical areas (see physical risks below). In turn, mitigation actions that would succeed in stabilising climate change will require a very fast and large transformation of both industrialised and developing economies (e.g. with regard to their energy, production and consumption systems) before 2040. This could generate both adverse impacts for some economic activities, but also new opportunities for others to strive (see transition risks below).

These facts about climate impact and climate mitigation are part of the knowledge developed over the years by the scientific community and the international policy community working on climate change. In well-functioning financial markets, future climate impacts eventually materialise in adjustments in the value of financial assets related to corporate and sovereign entities, as well as in liabilities for insurance companies. The magnitude of the adjustments and the range of sectors involved imply that climate risk is relevant for the financial stability of individual institutions. Further, because of the correlation of the impacts and the interconnectedness of institutions and economies it is also relevant for the financial stability of both individual countries and at the global level.

However, until very recently financial actors and markets seemed not to have internalised the knowledge about climate change in prices and risk metrics. Since the 2015 Paris Agreement, the financial sector has been increasingly engaging in the conversation on climate change. Financial supervisors now explicitly recognise climate change as a new source of financial risk (NGFS, 2019; Bolton et al., 2020) and a number of initiatives have emerged to encourage the disclosure of climate-related financial risks.

For instance, in 2017, the G20 Financial Stability Board (FSB) launched the Task Force for Climate-Related Financial Disclosure (TCFD) aimed to provide investors recommendations for disclosing climate change risks in their portfolios. In the same year, a group of central banks and financial regulators joined in the Network for Greening the Financial System (NGFS). In 2019, the NGFS recommended investors the introduction of climate stress-tests to assess the financial stability implications of their exposures to climate risks (NGFS, 2019), and in 2020 provided a set of climate relevant scenarios that investors should consider in their climate financial risk assessments (NGFS, 2020). Today, climate change is an element of the assessment of financial institutions' risk and, going forward, will be part of stress-testing exercises (EIOPA, 2019; Grippa et al., 2020).

In 2017, the European Commission (EC) created the High-Level Expert Group on Sustainable Finance (HLEG) that recommended the introduction of standards for the identification of sustainable investments. These recommendations were included in the EC its Action Plan for Sustainable Finance (2018) and guided the work of the EC Technical Expert Group on Sustainable Finance (TEG) and culminated in the publication of the EU Taxonomy, green bonds standards and low-carbon benchmarks in July 2020.

These important and unprecedented international initiatives show how relevant climate change has become for the financial stability agendas and for the mandates of financial supervisors. In particular, two channels of risk transmission from climate change to financial stability have gained financial supervisors' attention:

- *Climate physical risks:* climate change could damage physical assets and firms' production capacity, increasing the credit risk of banks, inducing financial losses for the insurance sector, and impairing governments' fiscal revenues and public debt sustainability.

- *Climate transition risks:* the transition to a low-carbon economy could lead to unanticipated and sudden adjustments of asset prices (both positive and negative) for entire asset classes leading to financial shocks for asset managers, institutional investors and banks' portfolios.

In the context of climate transition risk, the main threats for financial stability arise from a disorderly transition to a low-carbon economy (NGFS, 2019), i.e. a situation in which investors fail to fully anticipate the impact of the introduction of climate policies on their business models (Monasterolo and Battiston, 2020). Firms whose business and revenues depend on fossil fuel production or utilisation will suffer losses, giving rise to the so-called 'stranded assets' (Leaton et al., 2012; van der Ploeg and Rezai, 2020). These losses could then negatively affect the value of the firms' financial contracts and of the financial portfolios exposed to those firms (e.g., banks via loans, pension funds via equity holdings and bonds; see Stolbova et al. 2018). In addition, the high degree of interconnectedness of financial actors can further amplify losses for individual financial actors and for the financial sector, as occurred in the last financial crisis (Haldane and May, 2011; Billio et al., 2012; Battiston et al., 2012; Battiston et al., 2016).

Despite the sense of urgency and policy relevance of this topic, important gaps remain in the academic research in finance and economics in this area. This special issue aims at filling such gaps, by publishing original contributions that shed new light on the sources and the impacts of climate-related financial risks and analyse possible financial policies and financial instruments aiming at mitigating these risks.

This article is organised as follows. Section 2 discusses research challenges in macroeconomics and finance for the analysis of the relation between climate risks and financial stability. Section 3 presents the articles included in this special issue based on their main topic and stream of research. Section 4 concludes with recommendations for further steps of research in climate finance.

2. Climate risks and financial stability: research challenges and steps ahead

The analysis of the macroeconomic impact of climate change has received growing attention in the last decade, with a focus on the physical effects of climate change on the economy (see e.g. Noy, 2009; Burke et al., 2015; Hsiang et al., 2017; Diffenbaugh and Burke, 2019; Hallegatte, 2019). The analysis of the relation between climate risks and financial stability is more recent and is characterised by research gaps in two key areas:

1. The quantitative assessment of the impact of climate physical and transition risks on the macroeconomy and the financial system, considering feedback loops and drivers of amplification.
2. Financial actors and markets' internalisation of information about climate change in financial valuation and portfolio risk management.

2.1 Macroeconomic and financial impacts of climate change

To address the first research question, it is crucial to consider the nature of climate risk. The literature has highlighted the following key features of climate risk. First, it has been pointed out that this risk is systemic and non-linear (Bolton et al., 2020; Monasterolo and Battiston 2020, Dafermos, 2021) and is characterised by fat tails (see e.g. Weitzman, 2009; Ackerman, 2017). This means, that if not timely

addressed, it can lead to tipping points in the ecosystem that can generate prolonged socio-ecological and economic crises and hysteresis effects that prevent the system to return to its pre-crisis status (Steffen et al., 2018; Lenton et al., 2019), with profound implications for financial stability. Second, climate risk is endogenous, meaning that the realisation or not of the worst-case scenarios depends on the perception of risk of the agents involved (e.g. policy makers, investors, society) and their reaction to this perception (Battiston, 2019). Third, climate risk involves and affects at the same time (yet through different channels) several dimensions of the food-water-energy nexus, and the socio-economic activities related to that, increasing the complexity of impacts and policy reaction (Howarth and Monasterolo, 2016).

The characteristics of climate risk play an important role in the assessment of the macroeconomic and financial implications of climate change. They influence the design of shock scenarios, the shock transmission channels and the conditions for shocks amplification and persistence (i.e., reinforcing feedback loops). In this regard, a growing stream of research has discussed the limits of traditional approaches for the analysis of the macroeconomic and financial impacts of climate change and climate policies (Farmer et al., 2015; Mercure et al., 2016; Dafermos and Nikolaidi, 2019; Monasterolo, 2020).

In particular, macroeconomic models like the Dynamic Stochastic General Equilibrium (DSGE) models and the Computable General Equilibrium (CGE) models typically adopt strong assumptions about the clearing of labour and product markets, the agents' perfect foresight and rationality, as well as the equilibrium conditions in the economy. These assumptions are at odd with the deep uncertainty, non-linearities and the endogeneity that characterise climate risk. Moreover, these models normally relegate the role of money and finance to the sidelines. Although the role of the financial system has been incorporated in many DSGE models since the global financial crisis, in the vast majority of these models this has been done in the context of 'financial frictions' without considering the endogenous build-up of financial fragility (Gali, 2018), the endogeneity of money and the role of financial complexity and interconnectedness. Moreover, in these models, investment decisions are, de facto, backward looking because they are informed by price dynamics and metrics of resource scarcity that ignore the science-based scenarios of climate change impact and climate mitigation policies.

The omission of these aspects of real-world financial systems does not allow these models to be used for our understanding of the financial implications of the transition to a low-carbon economy. An additional implication is that these models may give a false sense of control of the ability of the economy to switch from high to low-carbon investments fast enough to achieve the Paris Agreement goals, and on the ability to manage climate-related financial risks. This, in turn, could lead investors and policy makers to take suboptimal decisions at the individual and collective level, with potentially severe implications for financial stability.

On the contrary, stock-flow consistent (SFC) and agent-based models analyse the macroeconomic and financial system as a complex adaptive system and they can easily incorporate the role on non-linearities, interconnectedness and disequilibrium phenomena. They also formulate explicitly the endogenous money creation process which plays a key role in the emergence of financial cycles.

2.2 Climate change and valuation of financial instruments

Empirical analyses of financial actors' and markets' reaction to climate change, and the pricing of climate change risk considerations in investment decisions, are still at an initial stage. In this regard, a main challenge stands in the classification of low-carbon and high-carbon assets and in the lack of standardised information on climate relevant characteristics of firms and financial products (e.g. green bonds, Environmental Social Governance (ESG)) across financial data providers; see Berg et al., 2019). Several empirical analyses on most well-known green finance instruments, i.e. green bonds, as well as on financial markets, find contradictory results on whether it pays to be green (Karpf and Mandel, 2018; Zerbib, 2019). Similarly, analyses of financial actors' and markets' reactions to climate news and policy announcements show that results are dependent on the definition of low/high-carbon assets considered (see e.g. de Greiff et al., 2018; Ramelli et al., 2018; Monasterolo and de Angelis, 2020).

The EU Taxonomy identifies sustainable investments, but it covers only low-carbon activities and it has not been implemented yet in the market. A standardized classification of investments that are exposed to the risk of carbon stranded assets is still missing. A growing number of rating agencies and financial companies have introduced indicators of environmental performance and carbon intensity, mostly based on backward-looking and self-reported information (e.g. on CO2 emissions). Alignment methodologies, such as PACTA (see https://www.transitionmonitor.com/), are contributing to analyse the gap between economic activities' preparedness to the Paris Agreement 2 degrees scenario, based on their energy technology endowments and future investment plans (e.g. CAPEX). However, they do not consider the financial risk associated with firms' investments across several climate mitigation scenarios, including scenarios of disorderly transition. The Climate Policy Relevant Sectors (CPRS) classification contributes to overcome this limitation. CPRS provide a granular classification of economic activities based on their climate financial risk exposure, considering their energy technology, role in the energy value chain and sensitivity to change in climate policy and regulation (e.g. in terms of costs, Battiston et al., 2017). Its high degree of granularity by economic activity (NACE 4-digit level) and energy technology (low/high-carbon) allows a direct mapping into the variables of climate economic models, whose scenarios have been recommended to investors by the NGFS (NGFS, 2020). Several financial institutions, such as the European Central Bank (ECB, 2019), the European Insurance and Occupational Pension Authority (EIOPA, 2018), the Austrian National Bank (Battiston et al., 2020b) and the European Commission (Alessi et al., 2019) have used the CPRS to assess investors' exposure to climate risk.

3. This JFS special issue on 'climate risks and financial stability'[1]

The special issue represents a collection of papers that analyse the impact of climate risks on financial stability using a variety of methodological approaches, including network modelling, mathematical financial modelling, financial econometrics, stock-flow consistent modelling and agent-based

[1] Within this special issue, a few manuscripts are still under review and thus, they could be added to the final list of accepted manuscripts.

approaches. The contributions of the special issue cover (i) the impact of climate transition policies on financial stability, (ii) the physical effects of climate change on the financial system, and (iii) the implications of climate change for pricing in financial markets.[2]

3.1 The impact of climate transition policies on financial stability

Within the theme of transition risks, Roncoroni et al. (2019) explore how banks and investment funds in Mexico can be affected under a range of climate policy scenarios. They do so by developing a novel approach that combines the climate stress-test framework (Battiston et al., 2017) with the NEVA framework for Network Valuation of Financial Assets (Barucca et al., 2020). They show that although the direct exposure of the Mexican financial system to CPRS is small, financial contagion effects can undermine financial stability under scenarios in which an abrupt implementation of climate policies is accompanied by weak market conditions.

Using Stock-Flow Consistent modelling, Dafermos and Nikolaidi (2020) and Dunz et al. (2020) analyse the transition effects of climate financial regulation and fiscal policies. They both show that the 'green supporting factor' − a financial regulation policy that reduces capital requirements for 'green' loans − can increase the financial fragility of banks since it leads to an increase in credit which is supported by less bank capital. Dafermos and Nikolaidi (2020) find that these transition effects of the green supporting factor are reinforced when the green supporting factor is combined with green fiscal policy (carbon taxes and green subsidies). They also find that a 'dirty penalising factor' − a financial regulation policy that reduces capital requirements for loans with a negative environmental impact − can have an adverse impact on the financial position of banks in the short run by increasing the loan losses of carbon-intensive companies.

Regarding carbon taxes, both Dafermos and Nikolaidi (2020) and Dunz et al. (2020) show that carbon tax policies need to be accompanied by 'revenue recycling' in order for the adverse financial effects of carbon pricing to be minimised. A particular innovation of the model of Dunz et al. (2020) is that it incorporates banks' climate sentiments. Their analysis suggests that, when banks anticipate the increase in the carbon tax by revising their lending behaviour, and their cost of debt (interest rate) for low and high-carbon firms, they mitigate the financial transition effects in the economy and finance.

3.2 Physical effects of climate change on the financial system

Four papers focus on the theme of physical risks. Dafermos and Nikolaidi (2020) and Lamperti et al. (2020) explore how climate finance policies can reduce the long-run financial instability that stems from climate-related events and the change in climatic conditions. Dafermos and Nikolaidi (2020) show that the green supporting and the dirty penalising factor can reduce physical risks since they lower carbon emissions by increasing credit availability for green investment and reducing credit availability for carbon-intensive investment. The impact is quantitatively small but is reinforced when the green supporting and the dirty penalising factor are implemented simultaneously. Using an agent-based

[2] Some articles of the special issue are still under review and might be added to the final version of this editorial piece.

macroeconomic model, Lamperti et al. (2020) find that policies that relax bank capital constraints for green loans can have more substantial beneficial effects on physical risks when they are implemented in conjunction with credit guarantees for green loans and carbon risk adjustments in banks' credit rating.

Garbanino and Guin (2020) investigate how banks reacted to a severe flood event in England in 2013-14. Their results show that banks did not take ex post into account flood risk in their valuation for mortgage refinancing and in their decisions for the level of the interest rate and amount of credit provision. A potential reason for that is that banks interpreted the flood event as a one-off occurrence. This indicates that the pricing of physical risks in mortgage lending has probably been limited so far.

Flori et al. (2020) explore empirically the interactions between commodity prices, climate-related variables (like rainfall and temperature) and an index that measures the degree of financial stress in capital markets. They do so by using a combination of a multidimensional graph-theoretical approach with standard econometric techniques. Their results suggest that climate-related variables affect financial stability through the impact that they have on commodity prices.

3.3 Implications of climate change for pricing in financial markets

Fatica et al. (2020) investigate econometrically if the yields at issuance are lower for green bonds compared to conventional bonds. They find heterogeneous effects: while yields are lower for supranational institutions and non-financial corporations, there is no difference between the yields of green bonds and conventional bonds in the case of financial institutions. They also find that green bond yields are lower in the case of repeated issuers of green bonds and when there is an external review of the green bond certification process. An additional finding is that those banks that issue green bonds tend to reduce their lending to carbon-intensive sectors.

Alessi et al. (2020) concentrate on the stock markets. Using a sample of companies listed on the STOXX Europe Total Market Index, they first show that investors accept a lower compensation for holding stocks of companies that disclose environmental data and have a lower emission intensity. They then estimate the losses of institutional sectors at the global level under a scenario in which the stocks of companies that have a strong environmental and disclosure profile outperform the stocks of carbon-intensive companies. They find that the losses are not quantitatively large, which is partly explained by the fact that their analysis does not consider second-round effects. They also show that a reallocation of assets towards greener assets could reduce these losses.

Climate and weather derivatives can be useful financial instruments for hedging climate-related risks. Bressan and Romagnoli (2020) introduce a copula-based pricing methodology for multivariate climate and weather derivatives. Employing data for Italy, they perform an empirical analysis which shows that the choice for the best copula differs depending on the season under analysis. They also illustrate the challenges related to the pricing of the climate and weather derivatives and point out that the mispricing of derivatives can actually increase physical risks, undermining financial stability.

4. Future avenues of research in climate finance

Understanding under which conditions climate change could affect financial stability and what role finance could play in amplifying or mitigating climate risks plays a main role for today's research and policy making in climate finance. This special issue represents the first contribution to fill these knowledge gaps, by embracing a diversity of approaches in macroeconomics and finance. The articles included in this special issue analyse the relation between climate risks and financial stability using network models, dynamic evolutionary models and financial econometric analyses. As such, they contribute to address some of the knowledge gaps that could not be analysed adapting traditional approaches in financial risk analysis based on backward looking information on CO_2 emissions, and expected values. These are not adequate to address the nature of climate change risk and could lead to misleading information for investors and policy makers.

In particular, the articles published in this special issue make original contributions to:

- identifying and assessing *transmission channels* of climate risks from the real economy to financial institutions portfolios, the *amplification mechanisms* within the financial system and *feedback effects* of climate-impaired financial institutions on the real economy;
- analysing to what extent market players price in climate risk across instruments and institutions;
- developing metrics of climate-related financial risk;
- assessing potential implications of climate finance policies, including climate-aligned central bank tools and macroprudential regulation;
- analysing climate-aligned developments in the financial markets (e.g. green bonds);
- the conceptual and analytical understanding of the conditions for the onset and the mitigation of climate-related financial risk.

Addressing the above issues is important *for the research community* in order to provide evidence-based results and to support policy makers in the design of effective strategies to cope with climate-related financial risk; *for financial supervisors,* to introduce climate risks in their financial risk assessment tools (including stress tests) and prudential policies, and to deliver on their prices and financial stability mandate; *for investors,* to disclose and assess climate risks in their portfolios, and to introduce climate change considerations in their investment decisions; *for policy makers* to introduce effective climate policies for an orderly low-carbon transition, considering which economic sectors and financial actors are vulnerable yet relevant to climate policy introduction. Thus, our choice of embracing methodological innovation is motivated by the need to analyse the complexity of the relation between climate change, the economy and finance, to inform the introduction of climate policies and financial regulations aimed to preserve financial stability.

This special issue should be intended as a first step to the improvement of our understanding of climate risks and financial stability. Research steps ahead include:

- the consideration of climate-related financial risks in the context of the COVID-19 crisis and the design of COVID-19 recovery policies aligned to the climate targets;
- the analysis of the conditions under which finance could be a driver or a barrier to the low-carbon transition, e.g. by amplifying risks. Modelling the ambivalent role of finance in climate mitigation

scenarios is fundamental for the identification of climate mitigation pathways that permit the achievement of the Paris Agreement target (Battiston et al., 2020).

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