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Analysis

A Financial Macro-Network Approach to Climate Policy Evaluation

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A R T I C L E I N F O

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A B S T R A C T

Existing approaches to assess the economic impact of climate policies tend to overlook the financial sector and to focus only on direct effects of policies on the specific institutional sector they target, neglecting possible feedbacks between sectors, thus, underestimating the overall policy effect. To fill in this gap, we develop a methodology based on financial networks, which allows for analyzing the transmission throughout the economy of positive or negative shocks induced by the introduction of specific climate policies. We apply the methodology to empirical data of the Euro Area to identify the feedback loops between the financial sector and the real economy both through direct and indirect chains of financial exposures across multiple financial instruments. By focusing on climate policy-induced shocks that affect directly either the banking sector or non-financial firms, we analyze the reinforcing feedback loops that could amplify the effects of shocks on the financial sector and then cascade on the real economy. Our analysis helps to understand the conditions for virtuous or vicious cycles to arise in the climate-finance nexus and to provide a comprehensive assessment of the economic impact of climate policies.

1. Introduction

Climate change has been recognized as a main source of risk not only for ecosystems and societies but also for the performance of the real economy (IPCC, 2014) and for the stability of the financial system (Carney, 2015; ESRB, 2016). Indeed, in order to limit the negative impact of human activities on the climate, there is a need for a reallocation of private and public financial investments from carbon-intensive to low-carbon economic activities (HLEG-Sust-Fin, 2017). There is a broad consensus on the fact that such reallocation of financial capital is not possible through purely market-based solutions and that ambitious economic policies aimed to foster the transition to a low-carbon economy, i.e. climate policies hereafter, are needed (EC, 2015; Maxton and Randers, 2016). In turn, the introduction of climate policies comes with a significant risk for those financial investors who are locked-in into high-carbon investments (the so-called climate transition risk, Carney, 2015), and thus exposed to a loss of value resulting from "carbon stranded assets" (Leaton, 2012; Caldecott and McDaniels, 2014). Overall, the global climate "Value at Risk" (VaR) due to climate-induced physical damages has been estimated as approximately 24 trillion USD of lost financial asset (Dietz et al., 2016). Further, a climate stress-test of the financial system (Battiston et al., 2017) shows that the combined exposure of financial actors' equity holdings portfolios to climate-policy-relevant sectors (i.e. sectors that are directly or indirectly responsible for greenhouse gases (GHG) emissions and thus more vulnerable in case of climate policies) is considerable, reaching up to 45% of the equity portfolio of pension funds. In addition, financial actors' interconnectedness across the interbank market and other markets could amplify distress through reverberation effects, with potential implications on systemic risk (Battiston et al., 2017). Indeed, in a mild scenario, volatility on climate-policy-relevant sectors affects individual financial actors while in a severe scenario, systemic adverse effects could occur. These findings imply that the assessment of climate policies' impacts on the financial system is crucial.

This paper aims to investigate how economic shocks arising from the "too-late-and-too-sudden" introduction of climate policies (ESRB, 2016) can be amplified through feedback loops of chains of financial exposures in the economy. We start from the observation that climate change leads to technological and policy shocks that invalidate the Rational Expectations Hypothesis (REH). Indeed, there are several examples of climate-related technological and policy shocks on asset prices that market players are not able to fully anticipate even on average (Monasterolo et al., 2017). Examples of unanticipated technological shocks include the faster-than-expected decrease in renewable

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energy costs in last decade. Examples of unanticipated policy shocks include the fact that in 2014 most observers would not believe in the achievement of the Paris Agreement in 2015, while in 2016 most observers would not predict the subsequent US withdrawal from the Paris Agreement in 2017.

These examples imply that, at a time scale relevant for decision making, agents' expectations on prices can be incorrect, even on average. This fact contradicts the REH and implies the possibility of systematic mispricing of assets. In turn, the invalidation of the REH and the possibility of systematic mispricing has deep implications on the role of finance in the impact of policy shocks on the economy as a whole. Due to the fact that many markets are decentralized, the market players are exposed to counterparty risk through financial contracts. In these markets, the recovery rate r denotes the fraction of the nominal value of the contract that a party obtains from an obligor, in case of its default. If the REH does not hold and there is the possibility of systematic mispricing on a given asset class, then the recovery rate on the obligations of all actors directly exposed to that asset class can be significantly smaller than one, even in expectation. Since the obligations of those first actors are assets for the second group of actors, the expected value of the assets of the second group can be systematically overpriced. In a mark-to-market accounting environment where market players make decisions based on the expected value of their counterparties' obligations, the initial mispricing on a given asset class implies the propagation of potential losses along the chains of financial contracts (Battiston et al., 2016b,c; Bardoscia et al., 2017). Further, as we show in this paper, the presence of closed chains of contracts leads to feedback loops that not only propagate shocks from a sector to another but also amplify their magnitude. Because in today's economy financial contracts form intricate networks, and feedback loops are present at many levels, their role needs to be examined. In particular, climate policy shocks hitting actors in the financial system could cascade to those of the real economy, and the impact of this shocks could get amplified by the feedback loops that characterize the real-financial linkages. The process of financialization of the economy in the last two decades (Palley, 2016) suggests that the magnitude of the amplification effect could be increasing.

In contrast, standard economic models for climate policies' evaluation focus on the economic costs of climate policies (Nordhaus, 1993, 2016; Revesz et al., 2014), and in doing so, they tend to rely on the REH and to overlook the role of the financial sector. In particular, they neglect possible feedback loops between sectors and they are therefore unsuited to assess the full financial impact of climate policies on the economy. In order to fill this gap, we develop a methodology based on accounting principles and a multi-layer network analysis that aims to estimate the potential amplification of shocks along feedback loops consisting of closed chains of financial exposures among institutional sectors in the economy. Our approach contributes to understanding to what extent (possibly delayed) climate policies could lead to amplification effects in case of banks' high leverage and a recovery rate lower than one. We estimate the main reinforcing feedback loops between the financial sector and the real economy based on Euro Area balance sheet and cross-sectors data.

The paper is structured as follows. In Section 2, we provide a review of *related work*. In Section 3, we present the *analytical results* where we introduce our methodology based on multilayer financial networks for the analysis of direct and indirect effects of climate policies. In Section 4, we present the *empirical results* where we discuss data used in the study, and two mechanisms of climate policy shock transmission. We conclude with Section 5, discussing the contribution of our methodology to climate-policy evaluation, which is followed by *Appendix* section containing the proofs of the propositions and other details.

2. Related Work

Policy-makers and regulators could play a defining role in meeting the Paris Agreement by designing the right incentives, and by implementing the adequate policy mix for a smooth low-carbon transition. In the current policy debate, the most discussed climate policies (and thus the more likely to be introduced in the near-future, see HLEG-Sust-Fin, 2018) are as follows:

- Market-based solutions, such as a carbon tax, i.e. the introduction of a tax on carbon emissions produced by economic sectors and activities (CPLC, 2017),
- Green macroprudential regulations such as differentiated banks' capital requirements (Volz, 2017; HLEG-Sust-Fin, 2018),
- Green unconventional monetary policies, such as a green Quantitative Easing (QE) implemented by the central bank through the purchase of green assets (e.g. green bonds) from the banks (Campiglio, 2016; Monasterolo and Raberto, 2018; Barkawi, 2017).

In order for the financial sector to be a part of the sustainability solution, the discussion about the timing and magnitude of climate policies should explicitly target finance, for at least two reasons. First, the implementation of climate policies could imply shocks for the financial system, and, in particular, for those financial actors who are both vulnerable yet relevant (Monasterolo et al., 2017). Second, the transition of the financial sector towards sustainability, including portfolios' decarbonization and the introduction of novel financial instruments, is considered as a precondition to achieving the EU2030 energy and climate targets (HLEG-Sust-Fin, 2017). It follows that in order to design and implement effective and targeted climate policies, policy-makers need to rely on tools for economic policy analysis that provide information on the following:

- *The structure of the financial system and the relation between the financial system and the real economy* (e.g. households, firms, government).
- *How shocks generated by the introduction of climate policies could spread through the network* of interconnected financial actors (i.e. shock transmission channels), and from there to the sectors and agents of the real economy. Recent analyses show that the interconnectedness of financial institutions could amplify both positive and negative shocks and significantly decrease the accuracy of estimations of default probabilities (Battiston et al., 2016a,b), thus, increasing the complexity of risk estimation.
- *The presence of reinforcing and balancing feedback loops and their effects through direct and indirect shocks' transmission channels.* For instance, the introduction of unconventional monetary policies (e.g. a green QE aimed to scale-up green capital investments) could induce shocks on the financial system (e.g. financial stranded assets) that could then affect the real economy (e.g. via shifting to green investments).

The concept of feedback loops is fundamental and is at the core of the analysis of the mechanisms driving the behavior pattern of a system over time (Sterman, 2000; Meadows, 2008). The analysis of feedback loops at work in a system allows to identify the presence of three main elements for climate policy analysis:

- time delays between the imposition of a shock and further shocks due to the agents' reactions,
- tipping points beyond which the characteristics of the system could dramatically change, and
- the presence of reinforcing mechanisms, which often give rise to problems of path-dependency.

In addition, the analysis of the dynamic interplay of feedback loops contributes to the explanation of emerging non-linear behaviors that are often not intuitively understood and that could give rise to emerging, unintended, macroeconomic consequences. Despite