Journal Pre-proof

Climate Sentiments, Transition Risk, and Financial Stability in a Stock-Flow Consistent Model

Nepomuk Dunz, Asjad Naqvi, Irene Monasterolo

PII: S1572-3089(21)00032-2

DOI: https://doi.org/10.1016/j.jfs.2021.100872

Reference: JFS100872

To appear in: *Journal of Financial Stability*

Received date: 12 March 2019
Revised date: 28 May 2020
Accepted date: 15 June 2020

Please cite this article as: Nepomuk Dunz, Asjad Naqvi and Irene Monasterolo, Climate Sentiments, Transition Risk, and Financial Stability in a Stock-Flow Consistent Model, *Journal of Financial Stability,* (2019) doi:https://doi.org/10.1016/j.jfs.2021.100872

Climate Sentiments, Transition Risk, and Financial Stability in a Stock-Flow Consistent Model☆

Nepomuk Dunz[a,b,*], Asjad Naqvi[a,b], Irene Monasterolo[a,c]

[a] *Vienna University of Economics and Business, Austria*

[b] *International Institute for Applied Systems Analysis, Austria*

[c] *Boston University, USA*

Abstract

A successful low-carbon transition requires the introduction of policies aimed at aligning investments to the climate and sustainability targets. In this regard, a global Carbon Tax (CT) and a revision of the microprudential banking framework via a Green Supporting Factor (GSF) have been advocated but two main knowledge gaps remain. First, the understanding of the conditions under which the CT or the GSF could contribute to the scaling-up of new green investments or, in contrast, could introduce new sources of risk for macroeconomic and financial stability, is poor. Second, we don't know how banks' *climate sentiments*, i.e. their anticipation of climate policies' impact in lending conditions, could affect the outcomes of the policies and of the low-carbon transition. To fill these knowledge gaps we develop a Stock-Flow Consistent model of a high income country that embeds an adaptive forecasting function of banks climate sentiments. Then, we assess the impact of the CT and GSF on the greening of the economy and on the banking sector analyzing the risk transmission channels from the credit market to the economy via loans contracts, and the reinforcing feedbacks that could give rise to cascading effects. Our results suggest that the GSF contributes to scale up green investments only the in short-run but it also introduces potential trade-offs on bank's financial stability. To foster the low-carbon transition while preventing unintended effects on Non-Performing Loans and households budget, the introduction of the CT should be complemented with redistribution welfare policies. Finally, if banks revise their credit supply conditions based on the firms' carbon profile ahead of climate policy introduction, they can contribute to align investments to the low-carbon transition and improve financial stability of the banking sector.

Keywords: climate sentiments, climate transition risk, bank loans, green supporting factor, carbon tax, low-carbon transition, financial stability, Stock-Flow Consistent model

E44, E40, E47, G21, Q01

1. Introduction

The transition to a low-carbon economy, and the achievement of carbon neutrality, requires both the scaling-up of low-carbon investments and the divestment from carbon-intensive investments (HLEG, 2018; NGFS, 2019). In the European Union (EU), it was estimated that reaching the EU 2030 climate and energy targets requires circa EUR 180 billion per year of new investments in renewable energy and energy efficiency (European Commission, 2018; HLEG, 2018). At the global level, the investments needed to achieve the low-carbon transition are estimated to be in the range of USD 1.6–3.8 trillion annually until 2050 for supply-side energy system investments alone (IPCC, 2018). However, despite a record high of USD 612 billion in 2017, global climate finance flows are still far from closing the green investment gap (CPI, 2019). On the one hand, the climate misalignment of investments hampers the feasibility to achieve the climate targets. On the other hand, it could drive new sources of risk for asset price volatility and financial stability, at the individual and systemic level (Monasterolo et al., 2017). Indeed, a disorderly low-carbon transition, i.e. the sudden introduction of climate policies and lack of full investors' anticipation (Battiston et al., 2017), could lead to a fast revaluation of carbon-intensive assets and thus of portfolios' performance (NGFS, 2019).

Already in 2015, the Governor of the Bank of England, Mark Carney, in his talk about the "Tragedy of the horizons" (Carney, 2015), pointed out that climate change could affect the performance of financial companies whose portfolios are exposed to climate risks, and could eventually trigger financial instability. Climate risk could impact the financial sector via two main channels of transmission, *climate physical risk*, i.e. climate-led extreme events leading to physical capital destruction, and *climate transition risk*, i.e. a disorderly introduction of climate policies that leads to an abrupt revaluation of entire pools of asset classes (Batten et al., 2016). These concerns were quantitatively assessed by Battiston et al. (2017)'s Climate Stress-test, which showed that individual investors' exposure to losses stemming from climate transition risks are large and could be amplified by network effects. In particular, climate transition risk could emerge in the credit market and cascade to economic agents via financial contracts (e.g. loans), with implications on firms and households' debt performance and banks' financial stability (Stolbova et al., 2018).

Nevertheless, there is growing awareness of the fact that investors are not yet pricing climate risks in the value of financial contracts, thus potentially increasing their exposure to such risks (Morana and Sbrana, 2018; Monasterolo and de Angelis, 2020). Main barriers for aligning investments to the low-carbon transition are represented by the deep uncertainty that characterizes the introduction of climate policies, and the characteristics of climate risks (i.e. forward-looking behavior, non-linear transitions, deep uncertainty and endogeneity), which makes it a new type of risk for economic analysis (Monasterolo, 2020). In this regard, it has been recently recognized that traditional climate economics and financial pricing models are not able to incorporate climate risk characteristics

☆ND, AN, IM want to thank Stefano Battiston (University of Zurich), Luca de Angelis (University of Bologna); the two anonymous reviewers and the editors of this special issue; the participants of the EAEPE conference 2019, the CliMath Workshop 2019, and the University of Zurich's Sustainable Finance conference 2020 for their useful comments and discussion. IM acknowledges the support of the Austrian Climate Research Program's (ACRP) 10th call project RiskFinPorto (KR17AC0K13647). ND, AN, IM acknowledge the support of the ACRP 11th call project GreenFin "Scaling up green finance to achieve the climate and energy targets: An assessment of macro-financial opportunities and challenges for Austria" (KR18AC0K14634). The usual disclaimer applies.

*Corresponding author: nepodunz@web.de. All authors contributed equally to this paper.

because they are constrained by equilibrium conditions, reliance on average values and most-likely shocks assumptions of complete information and lack of arbitrage (Battiston and Monasterolo, 2019a).

Academics, financial supervisors, and investors have advocated the introduction of stable and coherent fiscal policies to signal the market and to address the mispricing of climate-related financial risks. A global carbon tax (CT), i.e. a tax on the contribution of carbon-intensive activities to the production of CO2 emissions (Stiglitz et al., 2017; IMF, 2019), is among the most debated policies. The CT would increase the production costs for carbon-intensive companies but most governments have delayed the introduction of a CT so far (Monasterolo and Raberto, 2018, 2019; Bovari et al., 2018; Mercure et al., 2018; Rausch et al., 2011; Zachmann et al., 2018). To overcome this gridlock, the role of monetary policies and prudential regulations has been considered. The European Commission has proposed the revision of the microprudential banking framework, i.e., the introduction of a green supporting factor (GSF) aimed to lower capital requirements for green investments (Dombrovskis, 2018). This proposal was subject to criticisms with regard to its potential implications on financial stability (Thomä and Hilke, 2018; Dafermos et al., 2018a).

The IPCC report 1.5 degrees C (IPCC, 2018) pointed out that the time window left for policymakers to implement the low-carbon transition is narrowing fast. Thus, understanding the conditions under which a CT or a GSF could represent an opportunity for scaling up green investments, while preventing unintended effects on financial stability, is crucial. In addition, it is fundamental to consider how the banking sector could react to the policy announcement showing *climate sentiments* and affect the outcome of the policy implementation. Indeed, if the banking sector expects and/or trusts the climate policy introduction, it could anticipate it by revising its lending conditions, i.e., by decreasing (increasing) the risk pricing associated to green (brown) loans. This change in lending conditions would directly affect green and brown firms' profitability and investments, respectively by improving and worsening them. In contrast, if the banking sectors' climate sentiments will not play out, i.e. if the banking sector decides to ignore the information of the policy announcement thus not pricing it in its lending contracts, the policy itself might not achieve its goals (CISL, 2015; Trucost and ESG Analysis, 2018; Bank of England, 2018). Given the role that access to credit and credit conditions play in firms' investment decisions, a steep revision in interest rates could affect firms' profitability and their ability to repay loans. This, in turn, would affect Non-Performing Loans (NPL), banks' financial stability, and the country's economic performance.

In this context, two main knowledge gaps remain. First, our understanding of the conditions under which the CT or the GSF could contribute to scale up new green investments or, in contrast, introduce new sources of risk for macroeconomic (e.g. countries GDP) and financial stability, is poor. Second, we don't know yet how banks' *climate sentiments* could affect the outcomes of the climate policy implementation and of the low-carbon transition. These two elements are interconnected and potentially self-reinforcing. On the one hand, the way in which climate policies are implemented in the economy, and their credibility, could impact investors' performance by revising of firms' costs and profitability (e.g. banks' lending). On the other hand, the way in which investors respond to the information about the climate policy could determine the success of the low-carbon transition, as well as its implications for the financial sector.

We contribute to fill this gap by developing a stylized one high-income region, Stock-Flow Consistent (SFC) macroeconomic behavioral model that embeds an adaptive forecasting function of the banking sector's climate sentiments. We focus on the conditions for climate transition risk to emerge from the interplay between climate-aligned policies' implementation and banks' behaviours. The SFC model represents several sectors of the economy and the credit market as a network of interconnected balance sheets where accounting identities hold irrespective of agents' behavioral rules (Monasterolo and Raberto, 2018). Agents' behavioral functions are derived from standard economic literature. Thus, the model simulations results are determined by agents' behavioral functions and the balance sheet constraints proper of the SFC approach.

The model presents three main innovations on the state-of-the-art. First, we adopt a forward-looking approach to the pricing of climate risks in banks' lending contracts and firms' credit risk. This allows to account for the characteristics of climate transition risks in macroeconomic models, where the risk assigned to the firm (and thus the interest rate) by the banking sector is usually based on the firm's past performance. Second, we explore the interplay between banking sectors' climate sentiments and the climate policies' implementation. In our model, the banking sectors expectations about the effects of the policy implementation consider the future profitability of the brown and green firms. We build on traditional investors' sentiments analysis (Greenwood and Shleifer, 2014; Lopez-Salido et al., 2017) and extend it in the context of climate *transition* risk, in a modelling framework that allows to consider endogenously generated behaviors and financial frictions. Third, we assess the transmission channels of two main policies and regulations under discussion, i.e. CT and GSF, on banks' lending behavior (e.g. new green loans), the greening of firms' investments in the economy, and on banking sector's financial stability (consistently with Basel III (BIS, 2011)). As such, our approach allows us to identify the risk transmission channels from specific climate-aligned policies to economic and financial actors, the drivers of reinforcing feedbacks and the conditions for cascading losses via loans contracts.

We use the model to answer three research questions that are relevant for climate financial policies; (i) under which conditions a CT or GSF can foster green loans and investments in the economy, (ii) to what extent could trade-offs for financial stability emerge, and (iii), what role (if any) banking sectors' climate sentiments may play in fostering or hindering the expected effect of the policies on the green economy and on financial stability.

The paper is organized as follows. Section 2 provides a review of the state-of-the-art on climate risks and financial stability, with a focus on investors' climate sentiments and SFC models. Section 3 introduces the model, while Section 4 describes the three climate-aligned policy scenarios and their transmission channels. The results of the model's simulations are discussed in Section 5. Section 6 concludes discussing economic and financial stability trade-offs associated to the climate-aligned policies, and provides insights for research steps ahead.

2. Literature Review

2.1. Banks' stability after the Great Financial Crisis

In the aftermath of the 2008 Great Financial Crisis (GFC), academics and financial regulators have analyzed the drivers of financial risk, considering financial interconnectedness and complexity (Battiston et al., 2012, 2016).[1] Excessive credit growth received large attention given its role in

[1]See for instance the special issue in this journal on "Challenges for financial stability in Europe" (Galuscak and Horvath, 2018), see also Silva et al. (2017) for a literature review on systemic financial risk, and the JFS special

the GFC (Schularick and Taylor, 2012; Taylor, 2015). The conditions for excessive credit growth have been recently analyzed in the literature (Aikman et al., 2015; Alessi and Detken, 2018) and adapted in the Basel III accords that withstand current banking regulations (BIS, 2011). Indeed, the Basel III accords set minimum macroprudential requirements such as Capital Adequacy Ratios (CAR), capital buffers, and upper limits to leverage ratios. The implications of the introduction of these regulations on financial stability and on the economy are still debated. In particular, the literature has focused on (i) their role in increasing banking sectors' ability to absorb shocks, and (ii) their impacts on banking sectors' lending conditions and credit growth, and thus on GDP growth. Fratzscher et al. (2016) empirically analyze the impact of financial regulation with respect to banking sectors stability and credit provisioning. They conclude that tighter capital buffers have a positive effects on banking sector's stability. Several studies also find an inverse relationship between tighter banking regulation and growth of banking sector's lending to the real economy (Martynova, 2015; Aiyar et al., 2016; Ben Naceur et al., 2018). Similarly, stricter capital requirements could contribute to increase banking sector's lending rates, and thus impacting the real economy (King, 2010; Akram, 2014).

2.2. Climate-aligned policies and financial regulations

The Paris Agreement signed at the COP21 conference in Paris in 2015 (UNFCCC, 2015) highlighted the role of private investments in financing the transition to a low-carbon economy. Since then, the barriers and opportunities for scaling up green investments have started to be analyzed, with a focus on the role of climate-aligned policies and financial regulations (UNEP-FI, 2018).

In this regard, the discussions have focused on three types of measures, i.e., (i) market-based solutions to climate change, such as a carbon tax (CT), (ii) the role of green financial instruments, e.g., green bonds, (iii) and the revision of prudential regulations like emissions-based capital requirements, also referred to as the "green supporting factor" (GSF) (HLEG, 2018). These measures are expected to contribute to overcome the current mis-pricing of climate risks in investment decisions by signaling investors in the real economy and financial markets.

The introduction of a global carbon tax is the most debated market-based solution to climate change (Stiglitz et al., 2017). A carbon tax can be referred to as a Pigouvian tax (Pigou, 1920; Hassler et al., 2016) that aims to make polluters pay (both at the production and consumption level) by pricing their contribution to CO2 emissions. As such, a carbon tax would help to internalize the externalities associated with anthropogenic climate change, thus contributing to consider the impact of CO2 emissions on others, including on future generations. In addition, carbon taxes can be a source of revenues for the governments, giving them fiscal space to foster low-carbon investments (such as low-carbon infrastructures) or providing welfare support via 'revenue recycling' (Dafermos and Nikolaidi, 2019b; OECD, 2018; World Bank, 2019).

The central issues in the design of a carbon tax were identified in the tax rate, including adjustments to the rate over time; the tax base, i.e., the extent to which it should apply to emissions generated from fossil fuel combustion; the place of imposition of the tax, either directly on emissions or on

issue on "Network models, stress testing and other tools for financial stability monitoring and macroprudential policy design and implementation" for a proposition of new research avenues with respect to systemic risk analysis and financial stability implications (Battiston and Martinez-Jaramillo, 2018).

the embedded emissions inputs used in production; and the treatment of trade in energy-intensive goods (see Metcalf and Weisbach (2013) for a review).

So far, economic research has focused on the identification of the optimal carbon tax via the analysis of the social cost of carbon (SCC), i.e. the decrease in the discounted value of economic welfare caused by a 1 tonne increase in CO2 emissions. These analyses have been conducted with aggregated Integrated Assessment Models (IAM) that rely on cost-benefit approaches of climate damages, to determine the optimal emission path that maximises welfare (Nordhaus, 1993; Ploeg and Rezai, 2019). The approach and results obtained by aggregated IAMs have been criticised by several scholars, whose analyses support the introduction of a higher cost of carbon (Pindyck, 2013; Stern, 2013). For instance, using a revised DICE model, Nordhaus (2017) identifies the optimal temperature path in 3.5°C of global warming by 2100. This translates into a social cost of carbon and in an optimal carbon tax of USD 31 per ton of CO2 in 2010 USD. However, this temperature level is clearly beyond the climate targets of the Paris Agreement.

In 2017, Stiglitz and Stern published a seminal report (Stiglitz et al., 2017) on carbon pricing, highlighting that the optimal global carbon price would increase the more we wait for introducing it. They conclude that the explicit carbon-price level consistent with the 2°C target is at least USD 40–80/tCO2 by 2020 and USD 50–100/tCO2 by 2030, provided a supportive policy environment is in place.

In 2019, the World Bank identified fiscal policy reforms as the most powerful lever to reduce emissions in a cost-efficient way and serve as a foundation to deliver on important development goals (World Bank, 2019). In the same year, the IMF's (2019) Fiscal Monitor stated that large emitting countries should introduce a global USD 75/tCO2 carbon tax by 2030, and that "feebates", a self-financing mix of fees and rebates, should be introduced to face distributive effects, in particular in low-income countries. Since the introduction of a carbon tax has been delayed so far, a growing role for central banks has been advocated to signal the market in the low-carbon transition.

In the EU, the discussion focused on the European Central Bank's (mis)alignment to the EU2030 targets and the Paris Agreement, and its role in steering the allocation of assets and collateral towards low-carbon sectors to reduce the cost of capital for these sectors. The conditions for greening monetary policies (Schoenmaker, 2019), for example, via the preferential purchase of green bonds (Monasterolo and Raberto, 2017; Battiston and Monasterolo, 2019c) and by exploiting synergies with the European Investment Bank (EIB) have started being analyzed. Nevertheless, the lack of a standardized green taxonomy and green bonds' standards, the limited market share of green bonds on the bonds' market, the partial disclosure of climate-related financial information (Battiston and Monasterolo, 2019a), and the lack of understanding of banking sectors' climate sentiments, could weaken central banks' intervention, with unknown effects on financial stability.

Finally, the EC has proposed a revision of the microprudential banking framework the so called "green supporting factor" (GSF). This is expected to foster the banking sector to assign lower risk weights to green loans (Thomä and Hilke, 2018; Campiglio et al., 2018), thus improving the green lending conditions. Dafermos and Nikolaidi (2018) analyze the implications of differentiated capital requirements on carbon emissions and on financial stability but they don't find significant effects of a GSF on the reduction of carbon emissions.

In this context, understanding the conditions under which a reform of financial regulation could contribute to foster green investments while minimizing trade-offs for financial stability and inequality is crucial to inform effective policies.

2.3. Climate sentiments in the credit market

The role for investors' expectations of future profitability under climate physical and transition risk scenarios is gaining research and policy attention. This point is relevant because the banking sector could modify its lending conditions for green and brown sectors, with implications on firms' performance and the low-carbon transition.

Investors' sentiments have been studied in particular in the context of credit cycles. The financial instability hypothesis by Hyman Minsky (1977) and financial cycle analysis (Borio, 2014) has been a core foundation for concepts such as investors' sentiments (Barberis et al., 1998; Greenwood and Shleifer, 2014), diagnostic expectations (Bordalo et al., 2018), and credit-market sentiments (Lopez-Salido et al., 2017) to explain endogenous credit cycles.

In particular, Greenwood et al. (2016) and Bordalo et al. (2018) model credit cycles using extrapolative beliefs of investors. The resulting time-varying credit sentiments of investors can explain several empirical findings with respect to credit cycles, without considering the role of financial frictions. Further, Lopez-Salido et al. (2017) show that a predictable component of changes in credit spreads can be associated with investor's past sentiment, i.e. her dynamic beliefs about firm's default probability.

However, so far, the analysis of investors' sentiments has not considered the role of climate change, of the characteristics of climate risks and of financial risk, and their interplay. This is a main limitation because, on the one hand investors' expectations about climate policies could affect the success of the policies' implementation (via their investment decisions) and thus the achievement of the climate targets (Battiston and Monasterolo, 2018). On the other hand, the impact of the low-carbon transition on financial stability depend on banking sectors' considerations of climate change and climate-aligned policies in their business (CISL, 2015; Trucost and ESG Analysis, 2018). CISL (2015) and Trucost and ESG Analysis (2018) use experts' elicitation to provide qualitative insights about current investors' climate sentiments and their implications on smoothing financial stability impacts stemming from climate transition risk. So far, a formalization of banks' climate sentiments in the context of the low-carbon transition is missing.

In this regard, three research gaps deserve attention, i.e. the analysis of (i) the banking sector's reaction to the policies based on their expectations (ii) the risk transmission channels from changes in policies and regulations to the credit market and from here to economic agents, and (iii), the conditions for the onset of credit market instability (or resilience) via loans contracts. Addressing these research gaps would help financial regulators and Central Banks to identify financial instability implications of credit risk, and banks to manage their loans portfolio in the face of climate shocks, and thus avoiding the risk of losses driven by carbon stranded assets.

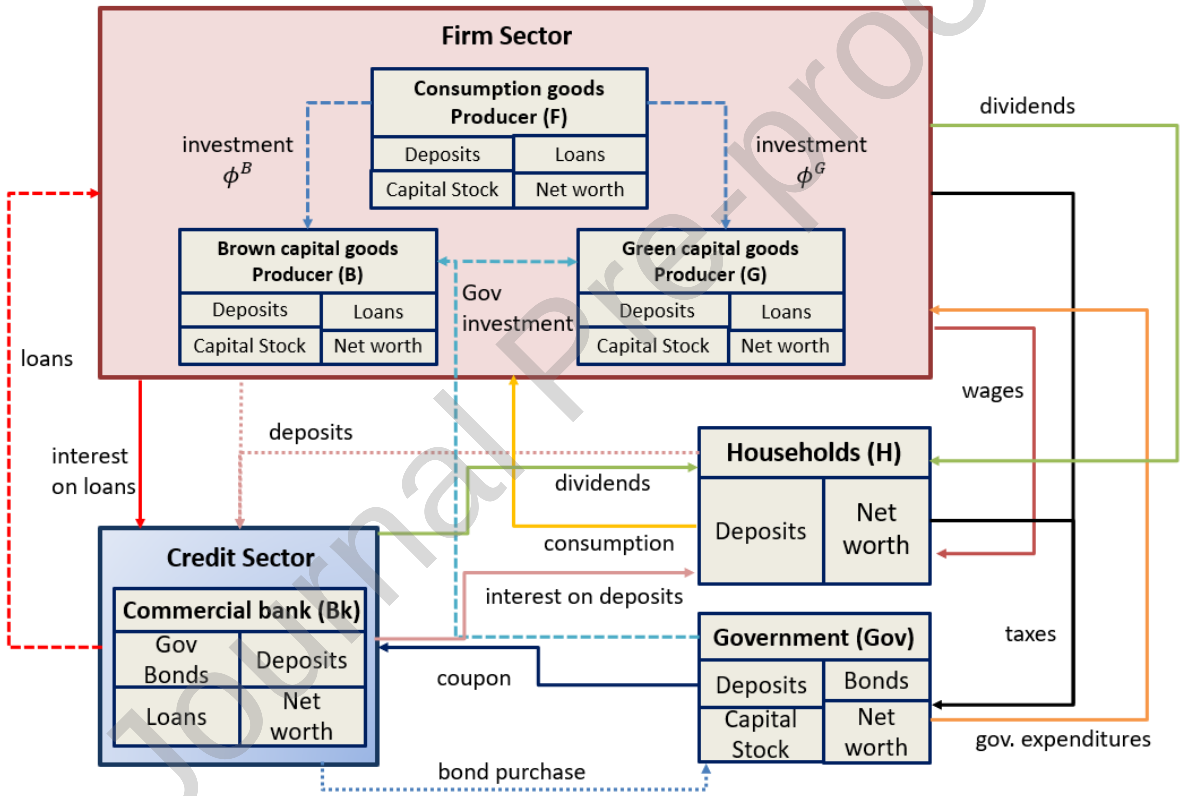
3. The Model

In this section we present the framework of the Stock-Flow Consistent (SFC) model, the main accounting and behavioral equations of its sectors, and the non-linear adaptive forecasting function of the banking sector's climate sentiments.

3.1. Model overview

We develop a stylized model of a high-income, one-region, economy composed of six sectors, that is, – households (H), a government (Gov), a commercial banking sector (Bk), a consumption good producer (F), a brown capital good producer (B), and a green capital good producer (G). Sectors are represented as a network of interconnected balance-sheets where accounting identities hold irrespective of the behavioral rules. The interactions among sectors' assets and liabilities shape a circular flow economy via capital and current account flows. The model parameters are calibrated based on values of the European Union (EU) economy (see Appendix C for parameter values)[2].

Figure 3.1: The model framework



Note: Flows of the model economy. For each sector, a balance sheet representation of assets and liabilities is provided. Dotted lines represent capital account flows, whereas solid lines represent current account flows.

The key relations are represented in Figure 3.1. Households purchase and consume consumption goods and receive income from wages and dividends from the firm sector. Households also earn deposit interests and banking sector's dividends. The firm sector, the banking sector and households contribute to the government's fiscal revenues via taxation. In turn, the government can use

[2]The parameter values are set to initialize a quasi-steady state. Therefore, we do not state the initial variable values but we focus on the relative movements across climate-aligned policy scenarios.

the fiscal revenues to cover current expenditures and public investments (e.g. in infrastructure, welfare), including the purchase of green and brown capital goods (as an "Entrepreneurial State", see e.g. Mazzucato and Penna 2016).

In addition, the government issues sovereign bonds to refinance its operations. The interest-bearing sovereign bonds are purchased by the banking sector. The firm sector is composed of two capital goods producers and a consumption goods producer. Capital goods producers are either brown or green, according to the emissions' intensity of their production, which is lower for the green capital goods producer. The consumption good producer could decide to use either green or brown capital goods (Monasterolo and Raberto, 2018).

Firms' production is driven by households and government's demand. The consumption good firm invests in capital stock with share ϕ_t^B in brown and the remaining share, $\phi_t^G = 1 - \phi_t^B$, in green capital stock. Firms finance their investments partially via retained earnings and partially by borrowing from the banking sector through interest-bearing loans (Monasterolo and Raberto, 2019).

The model framework is grounded in the accounting logic of SFC models (Godley and Lavoie, 2012; Nikiforos and Zezza, 2017). This means that all transactions among sectors are captured by a balance sheet (see Table A.2) and a transaction flow matrix (see Table A.3). All the relations and dependencies across heterogeneous sectors are represented by a set of behavioral equations included in the section below. The SFC logic requires that all entities have specific budget constraints and all transactions within the economy are zero-sum.

These features of SFC models allow us to understand the transmission channels through which the GSF or a CT could affect the pace of the low-carbon transition in the economy, and the conditions for GSF or CT to affect banking sector's (and government)'s financial stability by introducing new sources of risk via loan contracts.

The formalization of the model is supported by the following set of notations. The firm sector is represented by n goods where $n = \{F, B, G\}$ and $m = \{B, G\}$ represent the subset of brown and green capital good firms. Capital letters depict nominal values in current prices (for example, Y_t is nominal GDP), while lowercase letters stand for real values, or stocks (y_t, is real GDP). The subscript t denotes time and Δ represents first order time differences, for example, $\Delta r_t = r_t - r_{t-1}$. Parameters are represented by Greek symbols where the endogenous parameters are explicitly stated and indexed with the time t subscript.

3.2. The Firm Sector

The firm sector produces all the consumption and investment goods in the economy. This is represented by the general identity for GDP or total nominal output as:

$$Y_t = C_t^H + I_t + C_t^{Gov} \tag{1}$$

where C_t^H and C_t^{Gov} are total household and government expenditures on goods produced by the consumption good firm (F). The total investment, I_t, includes brown and green capital stock, which is produced by the brown capital good firm (B) and the green capital good firm (G) respectively. The demand for investments comes from, (a) the consumption good firm (I_t^F) that wants to increase the production capacity, (b), from the government, which invests in infrastructure and can invest in green/brown capital goods (I_t^{Gov}); and (c) the brown and green capital good sector (I_t^B, I_t^G) that build up their own capital stock. Formally, this can be defined as:

$$I_t = \sum_n I_t^n + I_t^{Gov} \tag{2}$$

For this categorization, the demand for output of each firm sector can be derived as follows:

$$\begin{aligned} Y_t^F &= C_t^H + C_t^{Gov} \\ Y_t^B &= I_t^B + \phi_t^B \left(I_t^F + I_t^{Gov}\right) \\ Y_t^G &= I_t^G + \phi_t^G \left(I_t^F + I_t^{Gov}\right) \end{aligned} \tag{3}$$

where $\{\phi_t^B, \phi_t^G\}$ are endogenously-determined shares of private and public investment demand for brown and green capital stock respectively (see Equations 5–7). By definition, $\phi_t^G = 1 - \phi_t^B$, implying that if one is estimated, the other can be derived as a residual.

Firms' production function requires two complementary inputs; Labor (N) and capital stock (K), where the total input demand is defined as:

$$Y_t^n = \mathbf{Min}[N_t^n, K_t^n] \tag{4}$$

Labor demand, N_t^n, and capital demand, $K_t^n = \phi_t^B K_t^B + \phi_t^G K_t^G$, are determined by productivities ϵ^N, and $\epsilon_t^B, \epsilon_t^G$ respectively.

We introduce a limited number of assumptions in order to keep the model complexity at a manageable level. First, we assume that labor productivity (ϵ^N) and consumption good productivity (ϵ^F) are constant in the short time frame of the model simulation. In contrast, productivity of green and brown capital good firms can change with respect to investment (see Eq. 7 below). This solution allows us to analyze the relative capital productivity changes that could be induced by climate-aligned policies. Second, only the consumption good firm (F) and the government (Gov) can decide whether to invest in green and/or brown capital stocks, via a portfolio allocation choice. Third, green (G) and brown (B) capital good firms use only the capital they produce themselves.[3]

3.2.1. Capital demand and productivity

The consumption goods firm (F) can use both the green and the brown capital goods for production. The demand for green or brown capital follows a portfolio choice determined by two variables, i.e the price and productivity. Formally, this can be represented as:

$$\Phi = \Lambda_0 + \Lambda_m \mathbf{Q} \tag{5}$$

[3] If these assumptions are relaxed, one would need to introduce aspects of endogenous technological change (see Naqvi and Stockhammer 2018), and input-output (I-O) structures (see Berg et al. 2015), that will further increase the complexity of the model and understanding of outputs.

where $\Phi = \{\phi_t^m\}$ is a vector of shares of brown and green capital goods. $\Lambda_0 = \{\lambda_0^m\}$ is the baseline demand for the two capital goods that is exogenously given. $\Lambda_m = \{\lambda_{ij}\}$ is a $m \times m$ matrix of elasticity coefficients for $\mathbf{Q} = \{p_t^m, \epsilon_t^m\}$, the price and capital productivity vectors for green and brown capital stocks respectively. The elasticity parameters Λ_m capture qualitative preferences, institutional conditions (i.e., quality of governance) as well as opportunities for substitution between green and brown capital goods. The column of Λ_0 sums up to 1, and the rows and columns of Λ_m sum up to 0, ensuring that adding-up constraints and symmetry conditions hold (Tobin, 1982). Assuming the total capital stock requirement is K_t, then the shares of green and brown capital stock can be derived as:

$$\begin{aligned} \phi_t^B &= \frac{K_t^B}{K_t} = \lambda_0^B + \lambda_{11} p_t^B + \lambda_{12} \epsilon_t^B \\ \phi_t^G &= \frac{K_t^G}{K_t} = \lambda_0^G + \lambda_{12} p_t^G + \lambda_{22} \epsilon_t^G \end{aligned} \tag{6}$$

Due to symmetry conditions, we only to estimate one equation where the second can be derived as a residual, for example, $\phi_t^G = 1 - \phi_t^B$. Using the standard accelerator principle, capital productivity ϵ_t^m evolves with respect to change in investments (Δi_t^m) (McCombie, 2002; Acemoglu, 2002; Acemoglu et al., 2012; Romer, 1990), such that:

$$\epsilon_t^m = \epsilon_{t-1}^m \left(1 + \gamma_\epsilon^m \Delta i_t^m\right) \tag{7}$$

where γ_ϵ^m is the adjustment parameter. We assume that the brown capital good producer has an initially higher productivity than the green capital good producer $(\epsilon_0^B > \epsilon_0^G)$ based on economies of scale for the brown sector and due to the higher cost of capital for green investments (HLEG, 2018). However, we also assume that productivity growth is higher for green relative to brown $(\gamma_\epsilon^G > \gamma_\epsilon^B)$, due to the fact that green capital goods have higher potential of efficiency gains that would allow them to catch-up to the brown sector (McCombie, 2002; Acemoglu, 2002; Popp et al., 2010; Lazard, 2018).[4] The consumption goods sector buys capital stock from capital good firms. Thus, we estimate its capital productivity as a weighted average of the productivity of the green and brown sectors:

$$\epsilon_t^F = \frac{K_t^{B,F}}{K_t^F} \epsilon_t^B + \frac{K_t^{G,F}}{K_t^F} \epsilon_t^G \tag{8}$$

3.2.2. Investment, Loans, and Defaults

Changes in demand result in changes in capital stock needs. Capital stock accumulation equals new investments net of depreciation (Eq. 9). Investments are determined by a target capital stock and firms preference for slack production capacity to adjust to short-run changes in demand (Lavoie,

[4] This is in line with several EU and national level policies which plan higher green R&D investment, and feed-in-tariff's (FITs) to boost the productivity of the green sector (European Commission, 2010, 2008, 2014; Official Journal of the European Union, 2013, 2009).

2014). Indeed, data from the EU manufacturing industry shows that the rate of capacity utilization in the EU28 is around 80% (FRED Economic Data, 2019; Eurostat, 2019a). Capacity utilization is a major indicator for price stability (ECB, 2007, 2010, 2019) and business cycles considerations (Greenwood et al., 1988; Dergiades and Tsoulfidis, 2007). We model this feature by assuming a target capacity utilization rate $\bar{u}$, while the actual sector-specific utilization rate is estimated as $u_t^n = y_t^n/(\epsilon_t^n k_t^n)$ (see Godley and Lavoie (2012); Dos Santos and Zezza (2008); Lavoie (2014)).

$$k_t^n = k_{t-1}^n(1-\delta) + i_t^n \tag{9}$$
$$i_t^n = \gamma_i(u_t^n - \bar{u})k_{t-1}^n + \delta k_{t-1}^n \tag{10}$$

Equation 10 represents the investment function. If firm products are in high demand, then the utilization rate goes up, implying firms approach full capacity. Therefore in order to maintain their target utilization rate, additional investments in capital stock are required. In contrast, if demand goes down, firms might decide to replace only the depreciated capital stock, or might decide not to engage in new investments. This would result in firms lowering their "functional" capital. This can also potentially result in stranded assets through large-scale divestment (Caldecott and McDaniels, 2014; Caldecott, 2018; Campiglio et al., 2018). In particular, the parameter γ_i implies that desired investment targets are met over several time periods. In nominal terms, investment requirement equals $I_t^n = i_t^n p_t^n$.

The firm sector finances investments via deposits V_t^n stemming from accumulated retained earnings RE_t^n and via banking sector loans L_t^n. Thus, the loans stock at a point in time is defined as:

$$L_t^n = L_{t-1}^n(1-\rho) + I_t^n - \eta V_t^n \tag{11}$$

where ρ is the repayment rate of loans, and η is the share of retained earnings utilized for capital stock accumulation.

Firms facing deteriorating economic conditions might not be able to meet their debt service obligations to the banking sector, which could then incur in non-performing loans (NPL). In case of NPL, the banking sector's recovery rate (R) can be smaller than 1, meaning that the banking sector is not able to recover the initial value of the loan (plus the interests). In case of firms' inability to repay the principal, the banking sector is affected via two channels: (i) it faces interest payments losses for the share of loans that are non-performing, affecting its profits (Eq. 28), and (ii), it has to adjust its balance sheet because we do not model asset or ownership transfers from the firm sector to the banking sector which could function as collateral. As a response to interest payment losses from a higher NPL ratio, the banking sector adjusts interest payments upwards for performing loans (Eq. 32) to price in the losses it might incur from NPL.

If NPL exceed the expected levels that the banking sector has already priced into its credit conditions (and displayed via the interest rate on the loan), the NPL might affect banking sector's financial stability (Kaminsky and Reinhart, 1999; Nkusu, 2011).

$$\Delta NPL_t^n = \Delta\xi_t^n L_t^n \tag{12}$$
$$\xi_t^n = \xi_{t-1}^n\left(1 - \frac{\Pi_t^n - \Pi_{t-1}^n}{\Pi_{t-1}^n}\right) \tag{13}$$

The share of NPL in total loans is determined by an endogenous parameter ξ_t^n (Eq. 13). We assume this parameter to evolve inversely relative to the rate of firm's profitability (Eq. 13) implying that firms are able to meet repayment targets if their profits are growing and the country's macroeconomic conditions are favorable (Nkusu, 2011; Klein, 2013; Jakubik and Reininger, 2013; Beck et al., 2015). This specifications allows us to proxy firm-specific and country-specific macroeconomic determinants of $NPLs$, as identified by Ghosh (2015).

3.2.3. Costs, Prices, and Profits

Firms use markup pricing (Eq. 17) over unit costs (Eq. 16) to determine the price of their products. As firms have two input factors for production, firms have two sources of costs that is, the wage bill WB_t^n and the costs of borrowing that we define as capital bill KB_t^n. Further, the policy dependent carbon tax T_t^{CT} enters firms' unit costs, as we assume the carbon tax to be passed through to the consumers (see Eq. 33 below).

$$WB_t^n = \omega \frac{y_t^n}{\epsilon^N} \tag{14}$$
$$KB_t^n = r_t^n(L_{t-1}^n - NPL_t^n) + \rho L_{t-1}^n \tag{15}$$

Equation 14 displays the wage bill, which equals sector-specific real output over labor productivity ϵ^N times the wage rate ω. For simplicity, we assume labor productivity and wage rates to be constant.[5]

Similarly, KB_t represents the cost of investment in capital. This can be defined as the interest paid on active loans (L_t^n) minus non-performing loans (NPL_t^n) plus the repayment of loans at rate ρ. We assume that in case of (NPL_t^n) firms don't pay interest on the amount of debt outstanding, thus reducing the expected profits of the banking sector. Thus, non-performing loans remain a liability for the firms and have to be repaid when economic conditions improve.

$$UC_t^n = \frac{WB_t^n + KB_t^n + T_t^{CT}}{y_t^n} \tag{16}$$
$$p_t^n = UC_t^n(1+\theta)(1+\tau^n) \tag{17}$$
$$\Pi_t^n = Y_t^n - T_t^n - T_t^{CT} - WB_t^n - KB_t^n + r_t^v V_{t-1}^n \tag{18}$$

where the tax T_t^n is a profit tax such that $T_t^n = (Y_t^n - WB_t^n - KB_t^n + r_t^v V_{t-1}^n)\tau^n$. Firms' profits (Eq. 18) are calculated as their income plus interest payments on firms' deposits, minus their labor and capital costs as well as tax payments to the government.

Profits are split into dividends ($Div_t^n = \pi\Pi_t^n$) and into retained earnings ($RE_t^n = (1-\pi)\Pi_t^n$). Dividends are passed onto households as capital income, while a fraction ηRE_t^n of retained earnings is used for investments. The remaining $(1-\eta)RE_t^n$ adds to firm's deposits V_t^n in the banking sector.

[5] The model structure allows to relax both assumptions by increasing wage and productivity growth endogenously. In this paper, we did not opt for this solution because it would result in additional level of complexity which does not directly affect the results. For an endogenous treatment of both these factors, see Naqvi and Stockhammer (2018).

3.3. Household sector

The household sector both owns the firms and bank as capitalists and provides labor as workers. They use their income for consuming goods (Eq. 21) or for saving for future consumption, thus accumulating wealth (Eq. 22).

$$T_t^H = \tau^H \left(\sum_n WB_t^n + \sum_n Div_t^n + Div_t^{Bk} + r_t^v V_{t-1}^H \right) \tag{19}$$

$$YD_t = \sum_n WB_t^n + \sum_n Div_t^n + Div_t^{Bk} + r_t^v V_{t-1}^H - T_t^H \tag{20}$$

$$C_t^H = \alpha_1 YD_t + \alpha_2 V_{t-1}^H \tag{21}$$

$$\Delta V_t^H = YD_t - C_t \tag{22}$$

Disposable income YD_t consists of the wages that are paid to workers from each of the firm sectors. Furthermore, all households receive dividends from the firm and the banking sector. Additional income for households is generated through interest payments on their bank deposits. Households pay income tax T_t^H on their total income, where the disposable income is calculated as an income net of taxes (Eq. 20).

3.4. Government sector

The government is in charge of the fiscal policy that consists of (i) collecting taxes from households and firms, and (ii) introducing a CT to make brown firms pay for their higher contribution to emissions in comparison to green firms, and collecting the carbon tax CT revenues (Eq. 23).

In general, fiscal revenues are used for covering government's running costs (Eq. 24) and government's infrastructure investment (e.g. motorways (brown) and railway system (green)) (Eq. 25) aimed to maintain public capital stock. Thus, as in modern economies, public investments support the deployment of private investments (Eq. 26).

$$T_t = T_t^H + T_t^{Bk} + T_t^{CT} + \sum_n T_t^n \tag{23}$$

$$C_t^{Gov} = \bar{G} + g_1 T_t \tag{24}$$

$$I_t^{Gov} = \sum_m \phi_t^m \left(\delta K_{t-1}^{Gov,m} + g_2 T_t \right) \tag{25}$$

$$K_t^{Gov} = \sum_m K_{t-1}^{Gov,m}(1-\delta) + I_t^{Gov,m} \tag{26}$$

$$\Delta GBond_t = C_t^{Gov} + \sum_m I_t^{Gov,m} + r^{gov} GBond_{t-1} - T_t \tag{27}$$

The demand decision for green or brown capital stock is also based on prices and productivity criteria defined by Equation 5. If government's expenditure exceeds the tax revenues, the government can issue bonds, which are purchased by the banking sector (Eq. 27). The parameters g_1 and g_2 are kept relatively small and make government spending pro-cyclical.

3.5. Banking Sector

The banking sector[6] holds private sector's deposits, provides loans to the firms, pays dividends to households and can purchase sovereign bonds. The banking sector only operates via the credit market in the model, implying that the banking sector's profits net of taxes stem only from the spread between the interests paid out on deposits, and the interests received for outstanding loans and sovereign bonds:

$$\Pi_t^{Bk} = \sum_n \left(r_t^{l,n} L_{t-1}^n - NPL_t^n \right) + r^{gov} GBond_{t-1} - T_t^{Bk} - r_t^v \left(V_{t-1}^H + \sum_n V_{t-1}^n \right) \tag{28}$$

Profits of the banking sector are distributed to households as dividends according to π ($Div_t^{Bk} = \pi \Pi_t^{Bk}$) and to banking sector's deposits constituting banking sector's equity, $E_t^{Bk} = (1-\pi)\Pi_t^{Bk}$.

The banking sector is not a simple intermediary between borrowers and savers but engages in endogenous money creation (McLeay et al., 2014) and is subject to leverage and capital requirements to avoid excessive exposure to financial risks. We proxy banking sector's financial stability as the Capital Adequacy Ratio (CAR) in our model (BIS, 2011). Risk enters into the banking sector's balance sheet through loans contracts to the firms. The banking sector assesses the risk related to each loan contract to a firm based on its past credit worthiness, which is reflected in a specific interest rate.[7] When it comes to green sector's lending, recent research shows that banks consider loans to the green sector as riskier than loans to the brown sector (Volz et al., 2015; Zuckerman et al., 2016; Nick Robins and McDaniels, 2016; Dombret and Le Lorier, 2017; Dhruba, 2018) thus applying a higher interest rate. In addition, the banking sector is not yet pricing climate risk in their loans contracts thus underestimating risks related to brown loans (i.e., the so-called stranded assets) (Delis et al., 2019). In line with this literature, we assume that the green sector is perceived as riskier compared to the brown sector and thus is subject to a higher initial base interest rate.

3.5.1. Capital Adequacy Ratio

The Basel III framework, that was formulated after the Great Financial Crisis of 2007–08, puts specific emphasis on the banking sector's liquidity, risk exposure and capital buffers within the objective of preserving banking sector's financial stability (BIS, 2011). By adopting Basel III's regulatory framework, the banking sector has to fulfill capital requirements and loan-loss provisioning, depending on quality and level of banking sector's assets (Pérez Montes et al., 2016) and to comply with a minimum Capital Adequacy Ratio (CAR).[8] The CAR is defined as bank equity over risk-weighted loans and indicates the liquidity of the banking sector with respect to loans that are considered as safe.

The banking sector achieves the target CAR through interest rate adjustments (King, 2010; Martynova, 2015), which also incorporate sector-specific credit conditions. This feature represents a

[6] The banking sector is the only investor in our model.

[7] Lending policy is typically backward looking in traditional SFC models. When modeling climate sentiments we relax this assumption by introducing forward-looking expectations.

[8] According to BIS (2011) total capital (Tier 1 & Tier 2 capital) must be at least 8% of risk-weighted assets at all times

proxy for limiting banking sector's credit supply to the real economy.

$$CAR_t = \frac{E_t^{Bk}}{\sum_n \chi^n L_t^n} \tag{29}$$

Equation 29 defines the banking sector's CAR as banking sector's deposits constituting its equity over risk weighted loans, where χ^n is the sector specific risk weight. As such, banking sector's CAR proxies financial stability of the banking sector in our model.

3.5.2. Interest rates

First, we assume that the banking sector sets two interest rates. These are the interest rate on deposits (r_t^v), and the base lending interest rate for firms (r_t^L). Both interest rates are determined by the exogenously-defined central bank interest rate $\bar{r}$ and by the banking sector's CAR level to ensure its profitability and compliance with the Basel III regulation. The deposit rate is estimated in Equation 30 as a moving average determined by the percentage difference between the actual CAR_t and the target CAR^T adjusted at a rate κ_0. Therefore, a lower CAR_t decreases the deposit interest rate. Accordingly, the base lending interest rate for firms (r_t^L) is estimated in Equation 31, whereas a lower CAR_t increases the base lending interest rate for firms.

$$\Delta r_t^v = \bar{r} + \kappa_0 \left(\frac{CAR_t - CAR^T}{CAR^T} \right) \tag{30}$$

$$\Delta r_t^L = \bar{r} - \kappa_0 \left(\frac{CAR_t - CAR^T}{CAR^T} \right) \tag{31}$$

Second, the banking sector sets sector-specific interest rates for all firms (r_t^n).[9] The interest rates depend on banking sector's lending base interest rate r_t^L, on the share of sector-specific NPL to loans ratio, on the expected profits $\tilde{\Pi}_{t+q}$ up to q periods in the future, on the corrections for forecasts for the current time period relative to actual profitability (see Section 3.6 for technical details), and on the potential impact of macro-prudential policies that affect the risk-weighting of loans for green and brown firms, i.e. the GSF.

In this framework, we introduce banking sector's climate sentiments, which are related to the banking sector's pricing of the CT and GSF announcements in their lending conditions, that is, by revising the interest rate for sectors accordingly (see Section 3.6).

$$r_t^n = \underbrace{r_t^L}_{\text{Base interest}} + \underbrace{\kappa_1^n \left(\frac{NPL_t^n}{L_t^n} - \tilde{\Pi}_{t+q}^n \left(\frac{\tilde{\Pi}_t^n - \Pi_t^n}{\Pi_t^n} \right) \right)}_{\text{Credit score}} + \underbrace{\kappa_2^n (\chi^G - \chi^B)}_{\text{Green supporting factor}} \tag{32}$$

The middle part of Equation 32 approximates a credit score. The NPL share represents banking sector's considerations of firms' past economic performance, whereas expected profits $\tilde{\Pi}_{t+q}^n$ approximate banking sector's expectations about firms' future economic performance.

[9] see Appendix F for a model version with credit rationing instead

3.6. Modeling banking sector's climate sentiments

In this section, we present the formalization of banking sector's climate sentiments and their inclusion in a SFC model. This represents an innovation on the state-of-the-art of macroeconomic and financial modelling of climate and financial risks. In traditional SFC and macroeconomic models, the banking sector assigns a risk to the firm and sets the interest rate based on the firm's past performance and on some economic outlooks. However, the economic and financial impact of climate transition risk cannot be observed on past data because we do not have examples yet of climate policy introduction. In addition, climate transition risks are characterised by deep uncertainty (Weitzman, 2014), path-dependency and complexity (Monasterolo and Raberto, 2019), and endogeneity (Battiston and Monasterolo, 2019b). Thus, modelling climate transition risks requires us to move from a backward-looking to a forward-looking perspective.

In our model, the banking sector forms expectations about the effects of the climate-aligned policy implementation (GSF or CT) on the future profitability of the brown and green firms. The banking sector is risk-averse and can decide to anticipate the policy impact by revising its lending conditions (via the interest rate) to the brown and green firms by tightening or loosening them respectively. This is what we call a scenario characterised by *climate sentiments*. In contrast, the banking sector can decide not to consider the information of the climate policy announcement, and thus can decide not to take any action. This is what we call a scenario characterised by *no climate sentiments*.

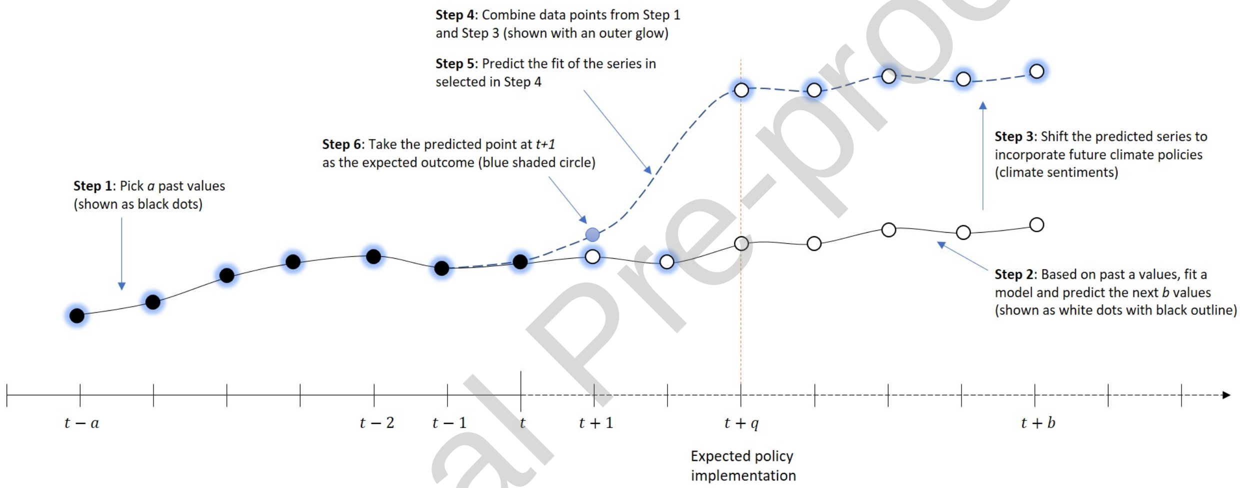
The SFC structure allow us to assess the macroeconomic and financial risk transmission channels of the climate sentiments. We use this approach to study to what extent banking sector's internalization of the announcement of future climate-aligned policies in their lending behavior could affect the low-carbon transition path. In particular, we are interested in analyzing the conditions for financial instability to emerge via $NPLs$ linked to climate impacts on firms' profitability. Indeed, if the banking sector starts to adjust its lending policies *after* the policy implementation, it can result in a misalignment of targeted goals further increasing transition risks.

The characteristics of climate transition risks prevent the banking sector to have perfect foresight. Thus, it can only make an educated guess about future outcomes, for example, whether profits or interest rates are expected to increase or decrease to inform its lending decisions. These are based on past firms' performance and on their trust about the future introduction of announced climate-aligned policies (Dell'Ariccia, 2001).

Such expectations about future outcomes are important for the banking sector, which might need to adapt certain indicators to deal with future climate-aligned policy and regulatory changes. A core variable in our model are differentiated interest rates for the green and brown sectors. Climate sentiments emerge when the banking sector starts to price the potential impacts of climate-aligned policies on green or brown firms' profitability, and thus on the risk associated to their respective loan contracts, reflected in the interest rate. Suppose at time t, the banking sector is informed that a climate-aligned policy, e.g. a Carbon Tax (CT), will be introduced at time period $t + q$ (where $q > 0$). As a result of the CT, the banking sector expects the profitability of the brown firms to decrease (due to the cost imposed by the policy), implying that firms' ability to repay loans might decline, thus increasing non-performing loans ($NPLs$). In this context, the banking sector is faced with two scenarios. First, it could wait to revise its interest rate at time period $t + q$ and adapt according to market condition then. This represents a conservative lending behavior that could lead to price volatility and potential financial instability for the banking sector when the policy is introduced. Second, the banking sector could be forward-looking and adjust the interest rates for the brown sector already at time t. Thus, the banking sector updates its lending policy *before* the climate-aligned policy is implemented in the future. As described earlier, we refer to the former as *no climate sentiments* scenario and the latter as the *climate sentiments* scenario.

While recent SFC literature has significantly advanced the banking sector's decision-making processes in a SFC framework (Monasterolo and Raberto, 2018; Dafermos et al., 2018b; Ponta et al., 2018), the treatment of forward-looking investment behavior is still missing.

Figure 3.2: An overview of modeling climate sentiments



Note: The x-axis represents the time line, where the current period is time t.

Figure 3.2 provides a representation of how the banking sector's climate sentiments are incorporated in our model. At a given time t, we observe past a time periods and use these values to forecast b future time periods. The figure reads as follows: the higher the value of a, the more risk-averse the bank is because it focuses on long-period past trends. Similarly, a lower value of b also implies risk-averse attitudes where forecasts are cautious. The predicted time series for $t + b$ periods can be adjusted to incorporate future expected impacts of policies. We can observe from Figure 3.2 is that if we incorporate climate sentiments, our expected values at $t + 1$ are higher than without climate sentiments. Thus, at this point we already internalize the future "jump" a policy might imply and start a smoother transition rather than face a "policy shock" at time period $t + q$. Once the modified series is created, we fit another curve to incorporate the $t - a$ past observations and modified $t + b$ observations. This curve, shown as the dotted line in Figure 3.2 gives us a value at time period $t + 1$ (solid blue dot) which is higher than the estimates without climate sentiments.

The steps shown in Figure 3.2 and described above are taken at every time step implying a continuously moving fitting function. Therefore climate sentiments continuously evolve depending on how the predicted series evolves and impact the decision making process of other sectors in the model. These five steps of internalizing climate sentiments' modelling are formalized as follows:[10]

- Step 1: At time t, $t-a$ past values are taken to generate a series $\boldsymbol{\Omega} = (\Omega_{t-a}, \ldots, \Omega_{t-1}, \Omega_t)$.
- Step 2: The data series $\boldsymbol{\Omega}$ goes through a fitting function $\hat{\boldsymbol{\Omega}} = f(\boldsymbol{\beta})$, where the estimated function takes the functional form Ψ defined by parameter space $\boldsymbol{\beta}$. For example, Ψ can be defined as a quadratic or a logistic function. From the estimated function, values for the next b time periods are recovered such that $\hat{\boldsymbol{\Omega}} = (\hat{\Omega}_{t+1}, \hat{\Omega}_{t+2}, \ldots, \hat{\Omega}_{t+b})$.
- Step 3: Climate sentiments are incorporated by modifying the predicted series $\hat{\boldsymbol{\Omega}}$ with a vector $\boldsymbol{Z}$. Assuming that firms' profitability is expected to change by $(1+\zeta)$ at point $t+q$ *if* the time step q lies in the prediction interval $q \in [1, b]$. The vector $\boldsymbol{Z}$ has a length of b in order to conform with the predicted series $\hat{\boldsymbol{\Omega}}$. The ith elements of vector $\boldsymbol{Z} = \{Z_{t+1}, \ldots, Z_{t+q}, \ldots, Z_{t+b}\}$ are 1 if $i < q$ and $(1+\zeta)$ if $i \leq q \leq b$ where $i = \{1, \ldots, q, \ldots, b\}$.
- Step 4: The predicted series *without* climate sentiments $\hat{\boldsymbol{\Omega}}$ and *with* climate sentiments $\hat{\boldsymbol{\Omega}}^*$ are combined with the original series $\hat{\boldsymbol{\Omega}}$ to generate two series $\tilde{\boldsymbol{\Omega}} = (\boldsymbol{\Omega}, \hat{\boldsymbol{\Omega}})$ and $\tilde{\boldsymbol{\Omega}}^* = (\boldsymbol{\Omega}, \hat{\boldsymbol{\Omega}}^*)$ respectively.
- Step 5: The combined series, $\tilde{\boldsymbol{\Omega}}$ and $\tilde{\boldsymbol{\Omega}}^*$, go through another fitting function to smooth the data series and eventually get $\hat{\hat{\boldsymbol{\Omega}}} = f(\boldsymbol{\beta})$ and $\hat{\hat{\boldsymbol{\Omega}}}^* = f(\boldsymbol{\beta})$ respectively. Here we also take the same functional form Ψ used in Step 2. From the second round of fitted series, $\hat{\hat{\boldsymbol{\Omega}}}$ and $\hat{\hat{\boldsymbol{\Omega}}}^*$, predicted points $\hat{\hat{\Omega}}_{t+1}$ and $\hat{\hat{\Omega}}^*_{t+1}$, are generated.[11]

Refitting the data in Step 5 allows to modify the predicted series ($\hat{\boldsymbol{\Omega}}$) to account for climate sentiments (Step 3). In a process that does not consider climate sentiments, this refitting is technically not necessary since the original fitted series would be sufficient to generate estimates at time period $t+1$. An illustrated example is provided in Appendix B.

Our approach represents a simple form of a Bayesian learning processes where priors and expectations are updated every time period as the series evolve. This forecasting module can be extended to any data series within the model to generate expectations of future values. The module can also be modified using more advanced time series analysis for example using ARCH or GARCH type processes (Azoff, 1994; Carol, 2001) where state-of-the-art models in financial econometric models typically build in time-varying parameters (Engle and Bollerslev, 1986; Engle, 2002; Engle et al., 2012; Engle, 2016).

The banking sector could also be modeled to be either more risk-averse or more risk-taking. The banking sector's risk profile affects the risk evaluation for the brown and green firms through the weights of the past observations used to make predictions for the future observations. Although the banking sector might be well-informed about the time of the policy announcement, it might decide not to take the information into account, or it could misjudge the effects of the policy. This would result in another feedback adjustment that might affect the banking sector's NPL and financial stability via a change in relative green/brown firms' profitability.

[10] See Appendix B for an illustration with an example.

[11] This can also be modified to generate averages of several predicted points. Robustness checks on different fitting functions show that the results do not change significantly.

In this context, the choice of this parameter space has relevant implications. In most forecasting models, the choice of parameter values or functional forms to be used is not unique in most financial forecasting models (Clements et al., 2004; Dantas and Cyrino Oliveira, 2018). Nevertheless, forecasting models now allow to deal with issues like noisy data series, high level correlations, behavioral endogeneity, volatility and non-Gaussian distributions (Timmermann, 2018).

4. Model Scenarios

We simulate and compare the impacts on green new investments, labor market, GDP and banking sector's financial stability conditions of three policy scenarios characterized by (i) the introduction of a GSF; (ii) the introduction of a CT *with* or *without* banking sector's climate sentiments and (iii) a Business as usual (BAU) scenario characterized by no change in climate-aligned policy and regulation.

4.1. Climate-aligned policies

4.1.1. Green Supporting Factor (GSF)

We consider the introduction of the GSF (see Thomä and Hilke 2018; Campiglio et al. 2018; Krogstrup and Oman 2019) that affects the banking sector's lending conditions in two ways. First, it introduces a reduced risk weight for banking sector's green assets, i.e green loans $(\chi^G - \nu) < \chi^B$ that, in turn, affects banking sector's CAR and thus reduces banking sector's overall interest rate setting (Eq. 29). Second, by facing lower liquidity requirements for green loans, the banking sector has incentives for lending out money to the green sector and to provide lower interest rates. This is captured by the difference in risk weights for green and brown firms $(\chi^G - \nu) - \chi^B$ that affects the green capital good firm's (G) interest rate in Equation 32. The rationale is that credit conditions play an important role on firm's ability to make new investments and thus to grow in market economies. Since debt service represents a considerable share of small and medium firms' costs, higher interest rates could affect firms' investment decisions, potentially slowing down economic growth (Juselius and Drehmann, 2015; Drehmann et al., 2015). In contrast, more favorable borrowing conditions could stimulate investments in two ways, i.e. directly via lower firms' capital costs and indirectly through higher sector-specific demand. This is the result of relative price effects due to lower capital costs.

4.1.2. The Carbon Tax (CT)

The carbon tax (Eq. 33) is a fiscal policy applied to sector B and sector F's nominal output, with the aim to increase production costs for brown capital goods and brown capital-based consumption goods. F has to pay a carbon tax on its production when it uses brown capital as an input (K_t^B/K_t). The carbon tax adds to firms' unit costs (Eq. 16) and reduces firms' profits (Eq. 18). However, via a mark-up pricing (Eq. 17), the higher unit costs are passed to the customers (i.e. the households and the government).

$$T_t^{CT} = \tau^{CT}\left(Y_t^B + Y_t^F \frac{K_t^B}{K_t}\right) \tag{33}$$

4.2. Scenarios' characteristics

Both the CT and GSF are aimed to foster green loans and investments to align the country economy to the EU2030 targets, proxied a share of 45% of green capital goods at the end of all scenarios' simulations. The scenarios are defined as follows:

1. A Green Supporting Factor (GSF) **SC1** which decreases the risk weights of green loans that enter the banking sector's CAR computation $((\chi^G - \nu) < \chi^B)$, allowing them to have a higher leverage ($SC1$). Hence, green lending becomes more attractive for the banking sector, leading it to reduce interest rates for the green capital good sector. This, in turn, induces higher green borrowing, all rest equal. In this scenario, the banking sector has no climate sentiments, i.e. it does not anticipate the change in the microprudential regulation.
2. A Carbon Tax (CT), (in line with Stiglitz et al. 2017 and IMF 2019), aimed at increasing the production costs for brown capital goods and brown capital-based consumption goods ($\tau^X > 0$). This, in turn, contributes to decrease brown firms' profitability with implications on their ability to pay interest and principal on their loans to the banking sector. In this context, the banking sector may or may not anticipate the introduction of the CT, as follows:
    (a) *A carbon tax and* ***no*** *climate sentiments* **SC2**. The banking sector does not anticipate the CT and keeps its current lending behavior, i.e. granting more favorable credit conditions to the brown capital sector because being considered less risky.
    (b) *A carbon tax and climate sentiments* **SC3**. The banking sector anticipates the CT and adjusts downwards the credit conditions for the brown capital good firm and the consumption good producer *before* the carbon tax is implemented. The climate sentiments reflect in the banking sectors' risk perception associated to green and brown firms and investments.
3. The policy scenarios are compared with a Business as Usual scenario **BAU**, where no GSF or CT are implemented. In addition, the banking sector doesn't change its current lending behavior nor conditions to green/brown firms (that is, no climate sentiments). Thus, in this scenario, no climate policy nor climate sentiments occur.

The model scenarios differ with regard to (i) the characteristics of the climate policy to be implemented, (ii) the banking sector's climate sentiments and, importantly, (iii) the channels and drivers of risk transmission.

4.3. Shocks' transmission channels

Our modelling approach allows to identify the climate-aligned policy shocks transmission channels and the shocks' impacts on the credit market and on the performance of agents and sectors of the real economy. This is crucial to assess the overall macroeconomic impacts of the climate policies and their interplay with investors' climate sentiments.

In the scenarios characterized by GSF and with banking sector's climate sentiments, the climate shock first hits the banking sector and then cascades to the brown and green firms via a revision of the loan contracts and lending conditions (worsening for brown/improving for green firms) via the interest rate channel. In contrast, in the scenarios characterized by the CT, the shock generates in the real economy via higher production costs for brown firms. The costs are transferred to households via mark-up pricing thus affecting household's budget constraint, and reducing overall demand. In addition, the carbon tax induces a strong relative price effect in favor of green capital goods, thus lowering the demand for brown capital goods in the economy. Overall, the carbon tax lowers the profitability of the brown firms (and thus its ability to repay loans) and cascades to the banking sector's lending conditions and associated risk (less favorable for brown firms).

Figures 4.1-4.3 show the transmission channels. Dotted line boxes represent the effects to the banking sector, while straight line boxes represent implications for the real economy. *Green* ↑ or ↓ signs indicate positive or negative changes for the green capital good sector, while *brown* arrows indicate changes for the brown capital good sector.

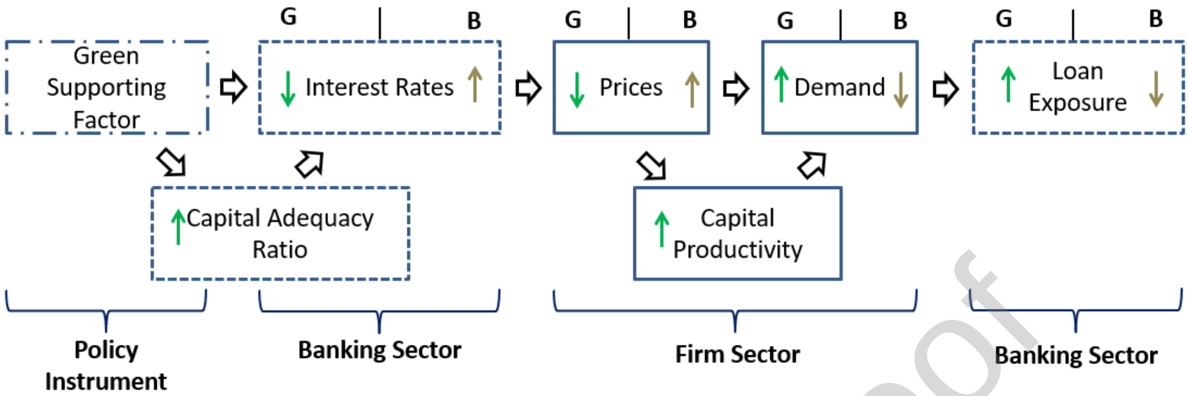
4.3.1. Shock transmission channel: Green Supporting Factor (GSF)

The transmission channel of the GSF, as simulated in $SC1$, is shown with Figure 4.1. The GSF lowers the risk weights for loans to green firms that enter the denominator of the CAR (Eq. 29). The resulting higher CAR leads the banking sector to set overall lower interest rates. Interest rates represent firms' cost of capital that affect their unit costs and are transmitted into goods prices via mark-up pricing. This means that interest rates affect the real economy in two ways. First, by influencing prices, interest rates affect households' budget constraint and thus ultimately final demand. As such, the overall lower interest rates induced by the GSF reduce firms' capital costs which translate via lower goods prices into increased aggregate demand. Second, different interest rates for the green and brown sector translate into distinct relative prices, which are the decision criteria for investments by the consumption good sector. In response to the GSF, the banking sector uses the additional credit leeway to reduce green interest rates for attracting now more favorable green loans (see Eq. 32). Being more price competitive, green capital goods demand and profits go up, which results in higher investment needs of the green capital good sector. This leads to a higher banking sector's loan exposure towards green lending. At the same time, new green investments stimulate green capital productivity gains, reducing prices of green capital goods even further and make brown capital goods less attractive. Via the relative price effect by directly lowering green capital costs, the GSF indirectly also reduces B's profits. Relying on profits and debt to equity ratios as a proxy for sector's ability to pay back its debt, the banking sector further adjusts interest rates accordingly, that is by further decreasing interest rates for green firms and increasing interest rates for the brown firms (Eq. 32). This reinforces the initial effects of the GSF described above.

4.3.2. Shock transmission channel: Carbon Tax (CT)

Figure 4.2 shows the transmission channel of the implementation of a Carbon Tax ($SC2$ & $SC3$). The carbon tax directly affects the consumption good sector and the brown capital good sector by making emission intense goods production more expensive. The CT has two effect channels, affecting the budget constraint of households on the one hand and relative prices of green and brown capital goods on the other hand. First, by assuming a mark-up on unit costs, the CT is transferred through the consumption good sector (F) to households in the form of higher consumption good prices (Eq. 17). In response, households facing a budget constraint, have to cut down consumption. The decrease in household demand has cascading effects via lower capital and consumption good production on GDP growth, firms' profits, lower employment and lower households' disposable income. Reduced household consumption in consequence of the CT affects all firms. Second, the CT affects relative prices by making brown capital goods directly more expensive. F

Figure 4.1: Green supporting factor's transmission channel



Note: G stands for green, B stands for brown capital good firms. Dotted line boxes represent the effects of the GSF on the banking sector, while straight line boxes represent implications for the real economy. Green upfacing (downfacing) arrows indicate positive (negative) changes for the green capital good firms G, while brown arrows indicate changes for brown capital good firms B.

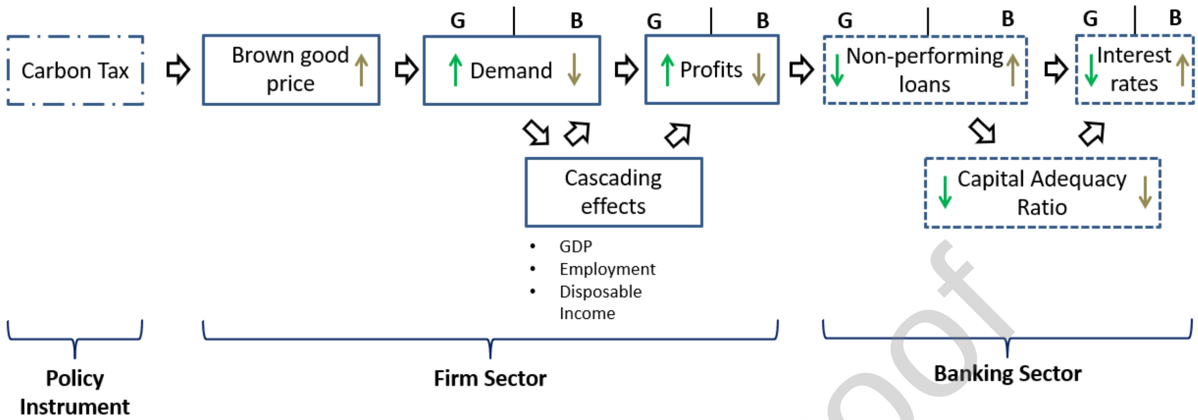
is sensitive to relative prices as captured by the portfolio choice specification (Eq. 5). Thus, F will decrease its share of brown capital goods and increase its share of green capital goods. As such, G indirectly benefits from the CT in terms of higher demand and profits, being now more price competitive. Higher demand for G translates into new investment needs, which stimulate green capital productivity gains. Those make green capital goods even more competitive, thus strengthening the relative price effect induced by the CT and lowering Bs demand and profits even further. However, the relative gains of G cannot fully make up for the overall household demand effect due to initially lower green capital productivity, higher green interest rates and previously installed brown capacity, resulting in overall GDP decline in the transition phase.

The CT impacts then transmit from the real economy into the credit sector. Lower firms' profits could lead to an increase in NPLs (Eq. 12), which in turn result in sector specific higher interest rates since the banking sector needs to price in the higher risk of loan default. The relative price effect described above leads the brown sector having even lower profits, facing higher interest rate increases. In contrast, the green sector relatively wins by facing higher demand and profits thus offsetting the interest rate increases which would result from the overall worsened economic conditions (Eq. 32). Higher interest rates represent higher capital costs for firms and transmit into higher prices, which reinforce the pressure on households' budget constraint. Further, higher $NPLs$ also affect banking sector's profits and equity, which lead to a lower CAR. In order to achieve its mandatory target level again, the banking sector also increases interest rates for all sectors, feeding back into the rest of the economy.

4.3.3. Shock transmission channel: Banking sector's climate sentiments

The risk transmission channel in case of banking sector's climate sentiments (that is, the banking sector anticipates the change in climate-aligned policy impact on its profits), as simulated in $SC3$, is represented in Figure 4.3. As a main difference with the GSF transmission channel, here climate sentiments lead the banking sector to increase interest rates for B thus directly affecting B. As

Figure 4.2: Carbon tax transmission channel



Note: G stands for green, B stands for brown capital good firms. Dotted line boxes represent the effects of the CT on the banking sector, while straight line boxes represent implications for the real economy. Green upfacing (downfacing) arrows indicate positive (negative) changes for the green capital good firms G, while brown arrows indicate changes for brown capital good firms B.

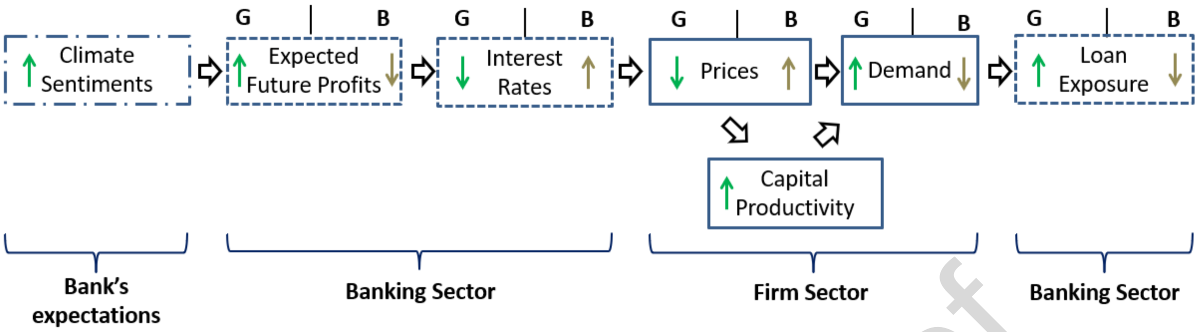
such, climate sentiments effects also originate in the banking sector, but work rather as an indirect brown penalizing factor by inducing the banking sector to anticipate the negative effects of a CT on brown firms' profits. Despite the banking sector doesn't know the exact timing and the magnitude of the CT, the banking sector forms expectations about the future (as described in Section 3.6). In particular, it expects higher (lower) future profits for the green (brown) capital good sector, and thus adjusts interest rates accordingly (Eq. 32). Lower (higher) interest rates transfer into lower (higher) prices, which affects capital and consumption goods' demands. F purchases a higher (lower) share of green (brown) capital goods, thus increasing (decreasing) output and actual profits in that sector. G employs additional capital stock to meet demand, which in turn supports increases in green capital productivity (Eq. 7). This contributes to reduce prices for green capital goods even further, since less green capital is required for producing one unit of green capital, eventually reducing its financing costs. Likewise, higher green capital productivity also directly stimulates F's demand (Eq. 5). As a response to changes in demand that translate into higher (lower) investment, the green (brown) capital good producer requires more (less) credit, leading to an adjusted banking sector's loan exposure towards the respective sectors (Eq. 11).

4.3.4. Shocks' comparison: Carbon Tax with or without climate sentiments

The difference between the two CT scenarios ($SC2$ & $SC3$) stands in the playing out of banking sector's climate sentiments *before* the introduction of the CT. A banking sector with climate sentiments revises its lending behavior before the CT implementation by changing the conditions of loans contracts for firms G, B, and F as shown in Figure 4.4.

In t, banking sector's climate sentiments $\tilde{\eta}_t$ ($SC3$) lead to lower interest rates for the green sector and higher interest rates for the brown sector. This results in an adjusted loan exposure $L^B > \tilde{L}^B$ and $L^G < \tilde{L}^G$ via the transmission channel described above and displayed in Figure 4.3. This, in turn, has different macroeconomic and financial stability effects once the CT is implemented in

Figure 4.3: Climate sentiments transmission channel



Note: G stands for green, B stands for brown capital good firms. Dotted line boxes represent the effects of the banking sector's climate sentiments on the banking sector, while straight line boxes represent implications for the real economy. Green upfacing (downfacing) arrows indicate positive (negative) changes for the green capital good firms G, while brown arrows indicate changes for brown capital good firms B.

$t + q$. Having F already adjusted its capital stock share due to the higher prices of brown capital goods relative to green capital goods, green capital productivity shows a convergence and the overall share of green capital goods at the time the CT is implemented is higher. The higher share of green capital in F's capital stock leads to a lower CT's cost for F. Consequently, households face lower prices, which grants them higher disposable income (and allow them to consume more), leading to higher GDP growth. Higher demand, in turn, leads to higher firms' profits, thus lowering the probability of NPLs, with positive effects for banking sector's financial stability. Similarly, the adjusted loan exposure in expectation of a CT contributes to decrease the probability of banking sector's NPLs, which materializes positively for banking sector's CAR being less volatile since interest rates have already been adjusted beforehand. Green capital productivity improvements before the carbon tax result in a higher green capital share of F. This reduces profits of B to a larger extent after the carbon tax implementation in the climate sentiments scenario ($SC3$). This in turn has effects on B's NPL ratio and granted loan interest rates being higher in the case of climate sentiments. Thus, banking sector's climate sentiments would allow a higher share of green capital goods, higher GDP growth, and lower NPL ratios for the green capital and consumption good firms after the implementation of the carbon tax. The firm sector B would face deteriorated financial and economic conditions, however, its scale would have been decreased due to the climate sentiments before the implementation of the carbon tax.

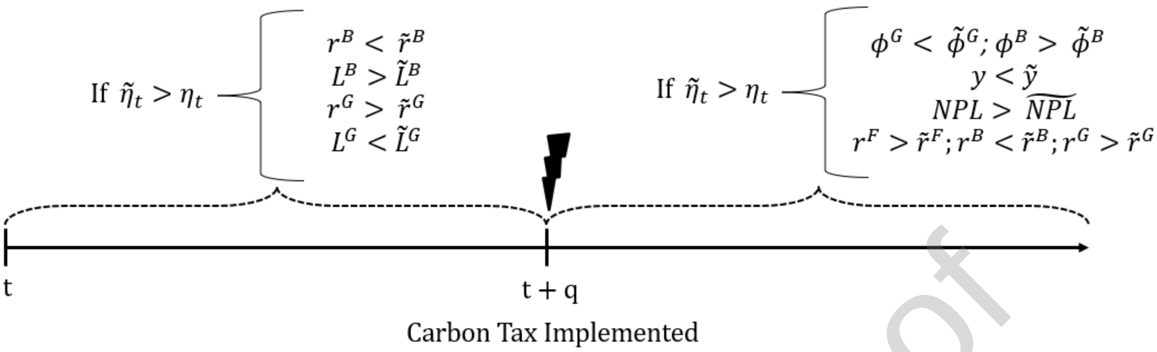
5. Discussion of results

This section presents the main results of the model's scenario simulations in Figures 5.1 to 5.4.

5.1. Macroeconomic effects

Figure 5.1a–c displays the effects of the CT and GSF on main macroeconomic indicators, including real GDP (Fig. 5.1a) and the relative prices in the green and brown sectors (Fig. 5.1b–c).

Figure 4.4: Time line of events and effect channels for climate sentiments



NOTE: $\eta_{t<1}$= Banking sector's expectations before carbon tax; r = interest rates; L = loan exposure; y = GDP; NPL = non-performing loans; ϕ = capital goods share whereas superscript B and G stand for *brown* and *green* respectively and $\sim$ represents higher climate sentiments of the banking sector.

5.1.1. GDP

In the GSF ($SC1$) scenario, the lending conditions to the green sector improve and lead to a decrease in green capital goods' prices. This, in turn, contributes to increase the green capital share of the consumption good firm and their productivity, which stimulates GDP growth. The introduction of the GSF, while targeting primarily the green sector, has implications also on the performance of the brown sector in the short-term. Indeed, the profits of brown firms decrease, thus increasing the probability of $NPLs$ in the brown capital good sector.

In addition, we can identify two side-effects of the GSF. First, in order to have a noticeable effect on the performance of the green sector, the decrease in interest rate for the green capital good sector introduced by the GSF must be large (Fig. 5.4). In absence of consolidated information on the green market (e.g. lack of standardized green taxonomy), this could drive risk of a green bubble. Second, and importantly, as our sensitivity analysis shows (Fig. D.2), even in presence of zero risk weights for green loans, the increase in the green capital good's share of the economy is limited. This means that the interest rate channel alone is not strong enough to scale up a relevant share of green investments. Therefore, prudential and monetary policies based on the interest rate channel should be complemented by other measures (e.g. fiscal policies) in order to fill the green investment gap.

In comparison to the BAU scenario, the introduction of a CT negatively affects real GDP but this effect is partially mitigated when the banking sector's climate sentiments emerge, and when the revenues of the CT are redistributed to the Households (see Appendix Appendix D). This is the result of two forces at play, i.e.:

- In the short-term, the CT increases the costs of brown products, which affect households' budget and lead to a decrease in aggregate demand;
- The short-term effects on the real economy are not compensated by a revision in the interest

rates conditions applied by the banking sector to green and brown companies, as in the case of the GSF (see transmission channel in Section 4.2).

. This contributes to explain the better performance of the BAU scenario over the CT in terms of GDP. However, we should also consider that the model does not incorporate long-term physical damages stemming from unmitigated climate change (IPCC, 2014; Burke et al., 2018), nor the medium to long term cost of economic adjustments[12].

5.1.2. Consumption good prices

Consumption goods prices increase with the introduction of a CT (Fig. 5.1b), thus tightening the budget constraint for households who do not get compensation, e.g. higher wages or welfare measures.

In contrast, the GSF ($SC1$) has smoothed effects on consumption goods prices because it does not directly penalize brown lending. This effect emerges when we consider the relative prices of green capital goods to brown capital goods (Fig. 5.1c). With the GSF, relative prices show a lower decline compared to the carbon tax scenarios ($SC2$ & $SC3$). This can be explained by the GSF transmission channel via interest rates that directly targets green investments (see 4.3.1).

5.1.3. Capital goods prices

The GSF directly affects green capital goods prices via improved lending conditions. However, brown capital good prices are only affected indirectly via the portfolio adjustments of the consumption good firm, in response to the improved lending conditions (and thus lower prices and green capital productivity gains) of the green capital good. This negatively affects sales and thus profits of the brown sector, with feedback effects on the banks' lending conditions and $NPLs$. In contrast, in both CT scenarios ($SC2$ & $SC3$) brown capital goods prices increase, leading to worse economic performance driven by the brown sector (see section 5.1.1). Green capital goods prices are only affected indirectly via portfolio adjustments in response to the relative price changes, and via the emerging green capital productivity gains. Overall, the CT channel of direct increase of brown capital good prices dominates the GSF channel of direct decrease of green capital good prices, resulting in lower relative prices for green capital goods under $SC2$ and $SC3$.

5.2. Banking sector's climate sentiments

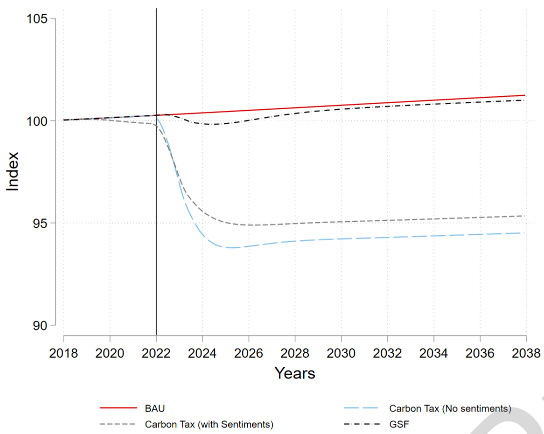
The banking sector's climate sentiments positively affect GDP via F's increase of its green capital stock share before the CT is implemented. This is the result of the relative productivity and price effects induced by the change in banking sector's interest rate conditions for the green firms. Therefore, bank's climate sentiments contribute to lower the cost of the CT introduction for F and to foster green capital productivity gains, and the low-carbon transition. Both effects positively contribute to GDP growth after the CT implementation.

It is important to notice that when banking sector's climate sentiments play out, the relative prices change already $before$ the introduction of a CT (Fig. 5.1b,c), driven by the banking sector's

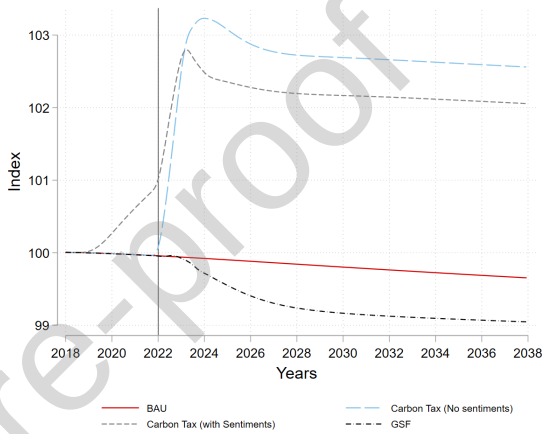
[12]In the appendix section Appendix D we provide an analysis of scenarios where the CT revenues are directly and entirely distributed to households, thus representing an additional instrument to support household income

expectations of lower profits for F and B that, in turn, increases in interest rates. This means that banking sector's climate transition risk considerations could foster the low-carbon policy effects in the economy. In addition, consumption good prices stabilize at a lower level after the introduction of the CT (b) compared to $SC2$, as a consequence of lower interest rates for the F in $SC3$ (Fig. 5.4b). This, in turn, contributes to increase households' purchasing power under $SC3$, and thus GDP growth in comparison with $SC2$.

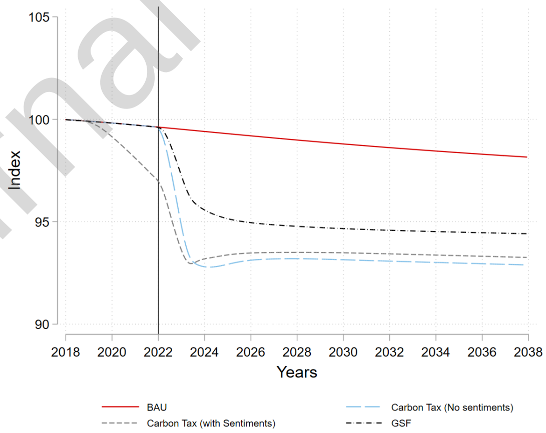
Figure 5.1: Macroeconomic Indicators



(a) Real GDP (y)



(b) Consumption Goods Prices (p^N)

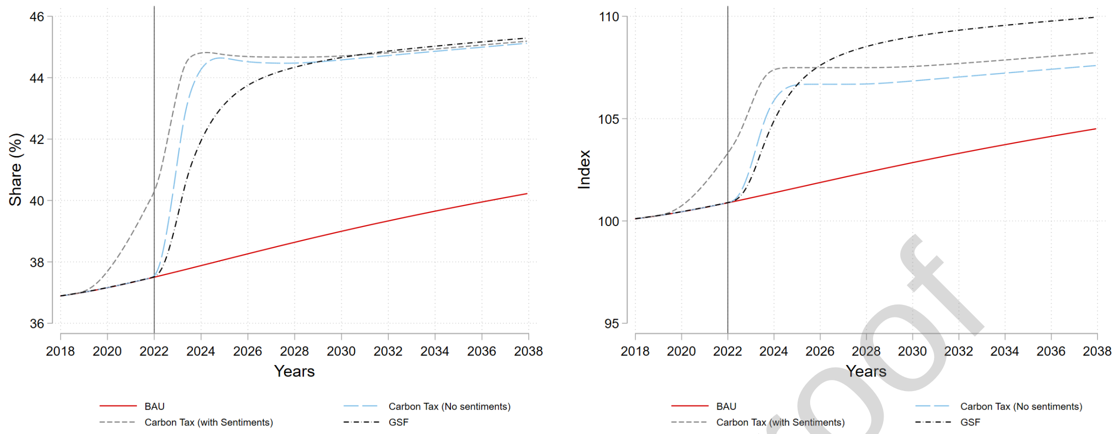


(c) Green/Brown Capital Goods Prices (p^G/p^B)

All climate-aligned policy scenarios are designed to achieve a 45% green capital share at the end of the simulation run to allow comparability of macroeconomic and credit sector effects (Fig. 5.2a).

Figure 5.2b shows the relative productivity gains of green capital with respect to brown capital. Bank's climate sentiments ($SC3$) improve green capital productivity earlier and stronger than in the scenario without climate sentiments ($SC2$), as a result of the timing of the reaction (compared to $SC2$) and the less negative effects for GDP. This, in turn, leads to higher investment inducing

Figure 5.2: Capital Goods Indicators



(a) Share of green capital (ϕ^G)

(b) Green vs. Brown Productivity (ϵ^G/ϵ^B)

green capital productivity gains. The GSF ($SC1$) ultimately leads to higher relative productivity improvements due to the relatively higher GDP in $SC1$ compared to the CT scenarios, and thus to higher overall investment. Even low relative price effects in the GSF ($SC1$) scenario (Fig. 5.1c) are sufficient, in combination to the higher overall investment needs, to push G's investment. Ultimately, this contributes to increase relative green productivity compared to the CT scenarios.

5.3. Financial stability

Figures 5.3a-f show the performance of the banking sector's financial stability indicators across the model's scenarios. Figures 5.3a-c present the trend of $NPLs$ ratios of the green and brown sectors. The $NPLs$ ratio for the green capital producer (Fig. 5.3c) decreases in both CT scenarios. This change occurs earlier and is more pronounced in the scenario with climate sentiments ($SC3$), as a result of a more pronounced GDP growth and a more competitive green capital good producer G. In contrast, the NPL ratios for the brown capital producer B (Fig. 5.3b) and the consumption good producer F (Fig. 5.3a) increases, with negative effects on GDP that cascade on the demand and profits. In particular, NPL ratio for F (Fig. 5.3a) is deeply affected by climate sentiments because F increased its green capital goods share before the introduction of the carbon tax. This is driven by the relative price signals that emerge from banking sector's climate sentiments and increase the interest rates for brown activities. By stimulating productivity gains in the green sector *before* the carbon tax introduction, climate sentiments contribute to smooth the negative effects on GDP when the carbon tax is implemented. Higher green productivity and a higher share of green capital employed have positive effects on Fs profits, compared to $SC2$.

The GSF indirectly affects B's NPL ratio (Fig. 5.3b). This is due to B's lower profits as a result of the better credit conditions for G and the related productivity effects. However, the NPL ratio is less pronounced than in the CT scenarios due to CTs direct impact on brown goods prices. The GSF's low impact on GDP (Fig. 5.1) smooths the increase in NPL ratio for B and F, and leads to a lower NPL ratio for G (Fig. 5.3c). With regard to the transmission channels 4.3), the introduction of CT contributes to decrease banking sector's lending to F and B (Fig. 5.3(d,f)), as a result of reduced credit demand, led by higher prices and lower household's demand and thus firms' economic opportunities. Climate sentiments strengthen this effect because they affect the price decrease for green capital goods more than in $SC2$ (see 5.1c). In addition, they generate stronger productivity gains for the green capital goods, which lead to lower investment demand for F (Fig. 5.3f) compared to $SC2$. Credit demand decreases in GSF ($SC1$) because while B requires lower loans in response to lower demand for its products, G and F require lower investment due to the productivity gains of the green capital good.

Figure 5.4 shows how the impacts of the climate-aligned policy scenarios and climate sentiments on banking sector's capital adequacy ratio (CAR) and interest rates. Expected profits, real profits and the CAR affect banking sector's interest rate setting (Eq. 30). Banking sector's CAR is more stable (in terms of volatility and trend) in $SC3$ after the introduction of the carbon tax (a), and is negatively affected by the GSF ($SC1$) as a result of the improved interest rates conditions for green firms (Fig. 5.4d).

The following macroeconomic and financial feedbacks emerge and contribute to explain the banking sector's interest rate setting. First, climate sentiments induce relative price changes in favor of G already before the CT is implemented due to banking sector's expectations. These relative price changes let the consumption good firm start to increase its green capital share before the carbon tax introduction, which in turn stimulates green capital productivity gains. The higher pre-tax green capital share means lower carbon tax payments for F and thus lower negative impact on GDP. Indeed, if banks expect and anticipate the climate-aligned policy, they can adapt their lending strategy and thus mitigate its negative impacts (e.g. on production costs and profitability). Second, the improved economic conditions in $SC3$ contribute to decrease the pressure on the CAR of the banking sector, resulting in a lower increase in interest rates in comparison with $SC2$. The result of this feedback effect can be noticed in the interest rates for B (Fig. 5.4c), G (Fig. 5.4d) and F (Fig. 5.4b) that are lower in the climate sentiments scenario ($SC3$) compared to the case without climate sentiments ($SC2$).

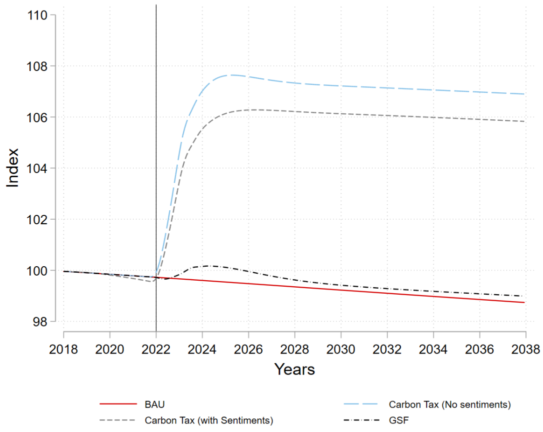
The GSF leads to an increase in interest rates for B and to a reduction of interest rates for F because it doesn't directly penalize B or carbon intense production of F (as a difference to the CT). In the GSF scenario, B's interest rate increases due to the relative price effect in favor of G, indirectly reducing its profits. We notice a strong interest rate decrease for the green capital goods firm in response to the GSF. This result should be taken with caution. Indeed, it could have negative effects on financial stability and lead to a green assets bubble if not supported by corresponding changes in real asset values.

Table 1 summarizes the results of the comparison of the three climate-aligned policy scenarios in terms of their impacts on GDP, relative prices, green capital share, CAR, and sector-specific NPL.

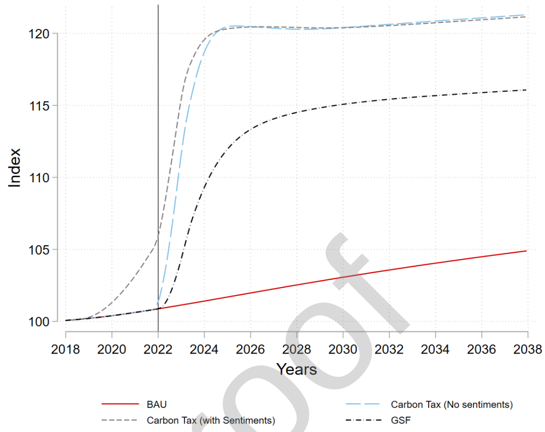
6. Conclusion

In this paper we have developed a Stock-Flow Consistent (SFC) macroeconomic model to analyze under which conditions government's fiscal policies (i.e. a Carbon Tax CT) and financial regulations (i.e. a Green Supporting Factor GSF) can contribute to foster the transition to a low-carbon economy, by signaling the banking sector. In addition, we analyzed to what extent unintended effects could emerge on economic competitiveness and banking sector's financial stability.

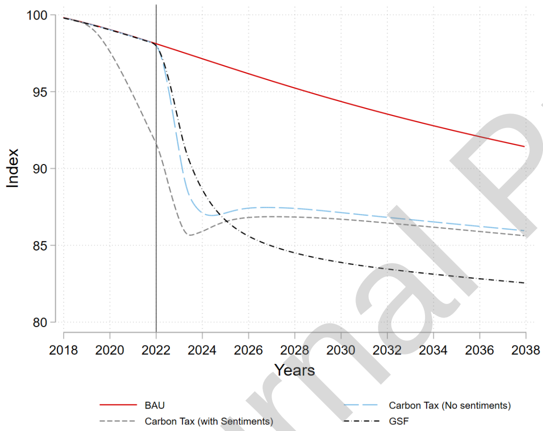
Figure 5.3: Bank Indicators



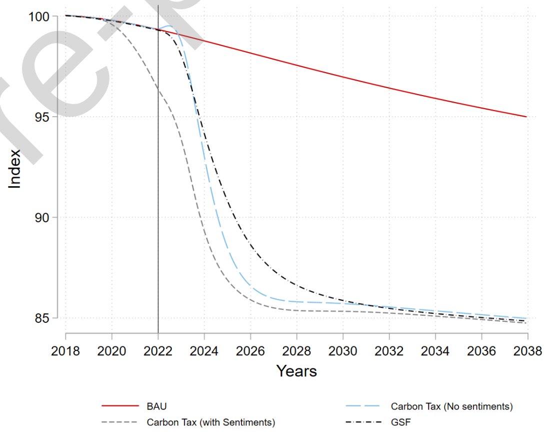
(a) Nonperforming Loans ratio (ξ^F) F



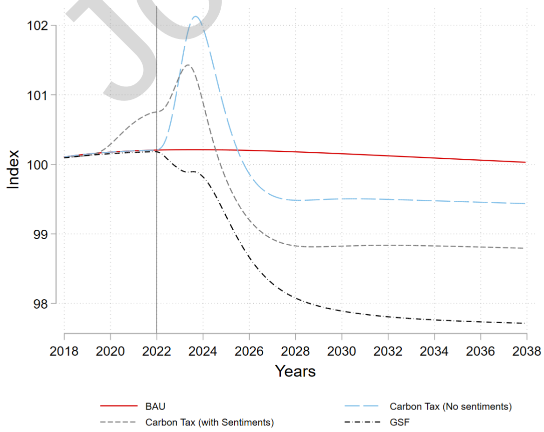
(b) Nonperforming Loans ratio (ξ^B) B



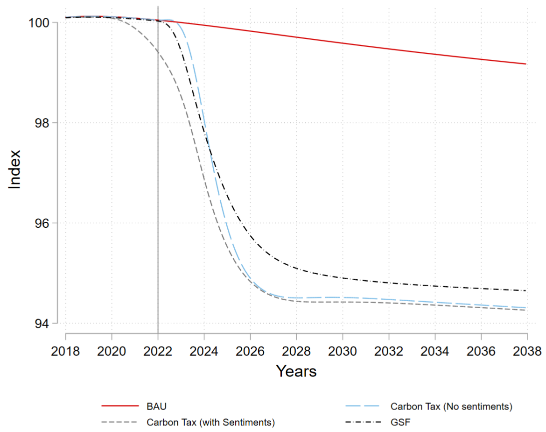
(c) Nonperforming Loans ratio (ξ^G) G



(d) Loan Exposure (L^B) B

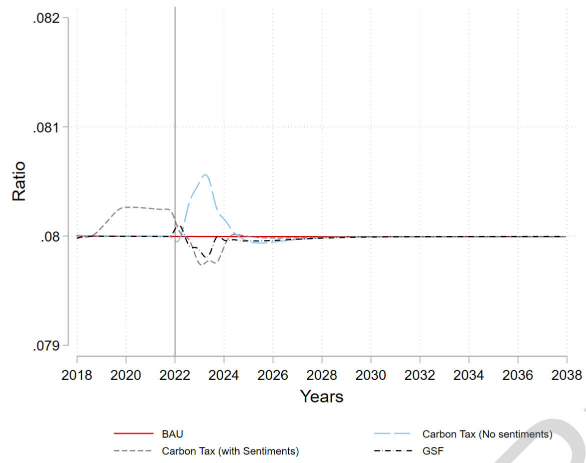


(e) Loan Exposure (L^G) G

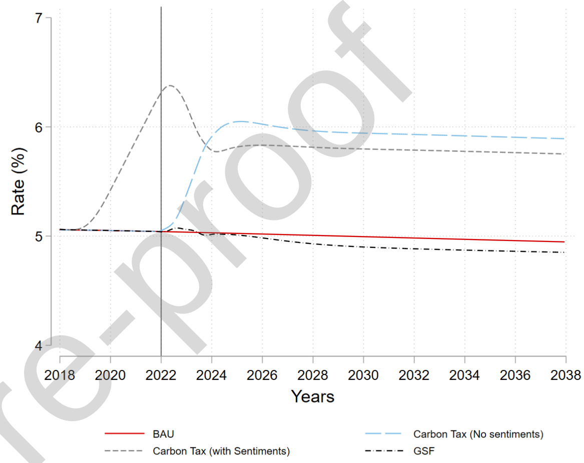


(f) Loan Exposure (L^F) F

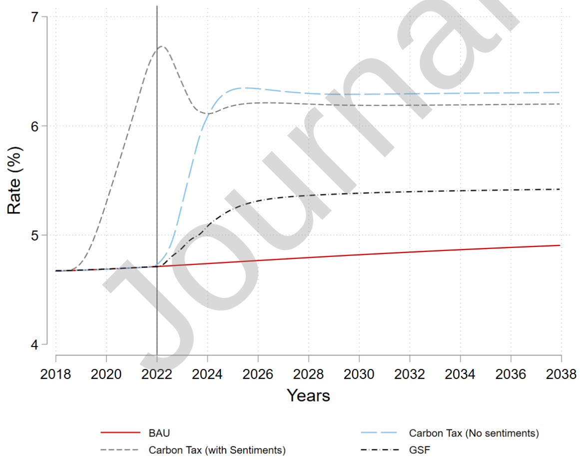
Figure 5.4: Interest Rates & CAR



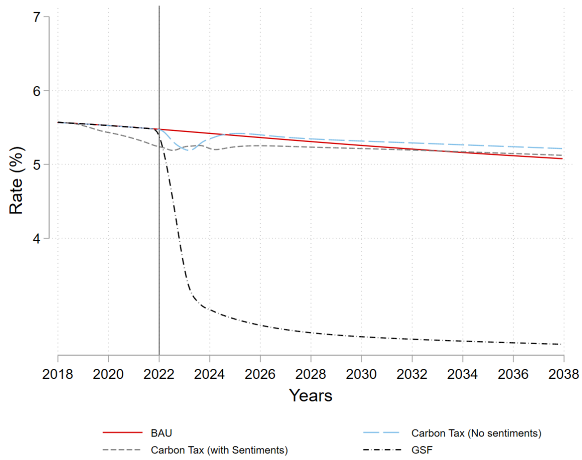
(a) Capital Adequacy Ratio (CAR)



(b) Interest Rate (r^F) F



(c) Interest Rate (r^B) B



(d) Interest Rate (r^G) G

Table 1: Climate-aligned policy scenarios classified according to their impacts

Impact on	*GSF* (*SC*1)	*CT* & **without** climate sentiments (*SC*2)	*CT* & **with** climate sentiments (*SC*3)
GDP (y)	∼	↓↓	↓
Relative Prices (Green vs. Brown) (p^G/p^B)	↓	↓↓↓	↓↓
Green vs. Brown Productivity	↑↑↑	↑	↑↑
Capital Adequacy Ratio Volatility (CAR)	↑	↑↑	↑↑
NPL F (NPL^F)	∼	↑	↑
NPL B (NPL^B)	↑	↑↑	↑↑
NPL G (NPL^G)	↓↓↓	↓	↓↓

Note: The table provides a classification of climate-aligned policy scenarios analyzed in terms of their impact on GDP, relative prices, green capital share, CAR, and sector-specific $NPLs$. ∼ indicates no significant impact, whereas ↑ and ↓ represent increases and decreases of variable values compared to the BAU, respectively. The number of arrows shows the relative impact strength of the scenario compared to the other scenarios.

Our model introduces a main innovation on climate-financial risks literature by explicitly modelling banking sector's *climate sentiments*, i.e., their anticipation of the impact of future climate policies on green and brown firm's performance. The analysis of banking sector's *climate sentiments* requires to adopt a forward-looking approach to firm's risk evaluation in order to embed the characteristics of climate transition risks, i.e. deep uncertainty, non-linearity, path dependency and endogeneity (Battiston and Monasterolo, 2019a). These characteristics make the reliance on past performance not adequate for financial risk assessment. However, in traditional SFC and macroeconomic models, the risk assigned to the firm by the banking sector (and reflected in the interest rate) is mainly based on the firm's past performance.

Our approach contributes to overcome this limitation by modelling the banking sector's expectations about the effects of the climate-aligned policy on the future profitability of the brown and green firms. Depending on its *risk aversion* and on its *willingness to consider the information about the climate policy* in its credit risk evaluation, the banking sector can decide to anticipate the policy impact by tightening (loosening) its lending conditions to the brown (green) firms. Climate sentiments playing out via the credit channel could generate cascading effects in the economy, due to the role that banks' lending conditions play both on firms' investments and on banks' financial stability.

Our results suggest that both the CT (*with* and *without* climate sentiments) and the GSF can signal the banking sector in the low-carbon transition. However, the climate-aligned policies differ in terms of the timing and magnitude of their direct effects on green investments and on financial stability, of their transmission channels, of their feedbacks in the system, and of the unintended effects that they might trigger.

On the one hand, the GSF contributes to foster new green investments via improved interest rate conditions for green firms, with a low overall impact on GDP, on prices and on $NPLs$. Nevertheless, three important trade-offs emerge triggered by the policy's transmission channel (i.e. the interest rate). First, in order to have a positive impact on new green investments, the decrease in interest rate for the green capital goods sector must be very large. Even in presence of zero risk weights for green loans, the increase in the green capital good's share of the economy is limited. Indeed, under the model and the current market conditions, the signaling effect via the interest rate channel alone is not strong enough to induce a relevant reallocation of investments towards the green sector (Fig. D.2), and should be complemented by other policies or measures. Second, large interest rates movements could weaken the banking sector's financial stability, and affect assets prices. This could lead to a *green* bubble, in particularly in absence of an implementable standardized green taxonomy for investments. Third, banking sector's financial stability is also challenged under the GSF by (i) the increase in the $NPLs$ ratio of the brown firms due their lower profits, as a result of the better credit conditions for green firms and the related productivity effects, and (ii) by the negative effect on the banking sector's CAR as a result of the improved interest rates conditions for green firms.

On the other hand, the introduction of a CT directly signals brown firms by increasing their production costs via the fiscal channel. This, in turn, indirectly affects the banking sector's lending policy and the relative profitability of the green and brown firms, with implications on the achievement of a smooth low-carbon transition (IPCC, 2018). Nevertheless, the overall effects on the economy and on the banking sector, as well as the emerging trade-offs, depend on how the CT is implemented. When the CT is not combined, neither with banking sector's climate sentiments ($SC3$) nor with government's redistribution of its revenues to households (Fig. D.1) or with green public investment (for example, see Monasterolo and Raberto 2019), the CT could have short-term negative effects on brown firms' performance. This, in turn, affects the banking sector's financial stability via higher share of $NPLs$ and lower demand for new loans due to the fall in GDP.

By anticipating the impact of the CT, the banking sector's *climate sentiments* can smooth the effect of the policy implementation, thus mitigating green/brown prices volatility. In particular, climate sentiments contribute to lower the cost of the CT introduction for F and to stimulate green capital productivity gains. Both effects contribute positively to GDP growth after the CT implementation. Further, the banking sector's CAR volatility and trend is stabilized due to the overall better economic conditions.

In conclusion, four main messages emerge from our analysis: (i) the GSF could represent an effective solution to scale up green investments only in the short term. In addition, it implies potential trade-offs on financial stability, even when considering only the lending channel; (ii) to foster the low-carbon transition while preventing unintended effects, the introduction of a CT should be complemented with welfare measures; (iii) climate sentiments could play a main role for a smooth low-carbon transition. Policy credibility is crucial to build trust of the banking sector, which in turn determines the successful implementation of the policy (and minimize the negative impacts on economic and financial instability) via its lending conditions; (iv) a single policy might not be enough to trigger the low-carbon transition at the pace needed (Stiglitz, 2019). In this regard, the conditions for synergies between GSF and a CT with and without climate sentiments, and green investment policies (i.e. the so-called European Green Deal) should be analysed.

Acemoglu, D., 2002. Directed Technical Change. Rev. Econ. Stud. 69 (4), 781–809.
Acemoglu, D., Aghion, P., Bursztyn, L., Hemous, D., 2012. The Environment and Directed Technical Change. Am. Econ. Rev. 102 (1), 131–166.
Aikman, D., Haldane, A. G., Nelson, B. D., 2015. Curbing the credit cycle. Econ. J. 125 (585), 1072–1109.
Aiyar, S., Calomiris, C. W., Wieladek, T., 2016. How does credit supply respond to monetary policy and bank minimum capital requirements? Eur. Econ. Rev. 82, 142–165.
Akram, Q. F., 2014. Macro effects of capital requirements and macroprudential policy. Econ. Model. 42 (2014), 77–93.
Alessi, L., Detken, C., 2018. Identifying excessive credit growth and leverage. J. Financ. Stab. 35, 215–225.
Arrondel, L., Lamarche, P., Savignac, F., 2015. Wealth effecs on consumption accross the wealth distribution: empirical evidence. ECB Work. Pap. Ser. June 2015, 1–59.
Azoff, E. M., 1994. Neural Network Time Series Forecasting of Financial Markets. John Wiley & Sons, New York.
Bank of England, 2018. Transition in thinking : The impact of climate change on the UK banking sector Transition in thinking. Tech. Rep. September 2018, Bank of England - Prudential Regulation Authority.
Barberis, N., Shleifer, A., Vishny, R., 1998. A model of investor sentiment. J. financ. econ. 49, 307–343.
Batten, S., Sowerbutts, R., Tanaka, M., 2016. Let's Talk About the Weather: The Impact of Climate Change on Central Banks. Bank Engl. Staff Work. Pap. 603.
URL https://www.bankofengland.co.uk/working-paper/2016/lets-talk-about-the-weather-the-impact-of-climate-chan
Battiston, S., Caldarelli, G., May, R. M., Roukny, T., Stiglitz, J. E., 2016. The price of complexity in financial networks. Proc. Natl. Acad. Sci. 113 (36), 10031–10036.
URL http://www.pnas.org/lookup/doi/10.1073/pnas.1521573113
Battiston, S., Mandel, A., Monasterolo, I., Schütze, F., Visentin, G., 2017. A climate stress-test of the financial system. Nat. Clim. Chang. 7 (4), 283–288.
Battiston, S., Martinez-Jaramillo, S., 2018. Financial networks and stress testing: Challenges and new research avenues for systemic risk analysis and financial stability implications. J. Financ. Stab. 35, 6–16.
Battiston, S., Monasterolo, I., 2018. The Climate Target Gap Is Widening. Can We Close It by Including Climate Finance in SSPs? SSRN Electron. J., 1–5.
Battiston, S., Monasterolo, I., 2019a. A carbon risk assessment of central banks' portfolios under a 2C aligned climate scenarios: Working paper presented at the Bundesbank workshop 'Scaling-up Green Finance: The Role of Central Banks' Nov. 8-9 2018. OeNB Work. Pap., 1–23.
URL https://ec.europa.eu/jrc/sites/jrcsh/files/paper{_}irene{_}monasterolo.pdf
Battiston, S., Monasterolo, I., 2019b. A Climate Risk Assessment of Sovereign Bonds' Portfolio. SSRN Electron. J., 1–25.
URL doi:10.2139/ssrn.3376218
Battiston, S., Monasterolo, I., 2019c. How could the ECB's monetary policy support the sustainable finance transition? FINEXUS Work. Pap. (input to Posit. Money Veblen's policy Rep. Aligning Monet. Policy with EU's Clim. Targets), 1–18.
URL https://www.finexus.uzh.ch/en/news/cspp{_}sustainable{_}finance.html
Battiston, S., Puliga, M., Kaushik, R., Tasca, P., Caldarelli, G., 2012. DebtRank: Too Central to Fail? Financial Networks, the FED and Systemic Risk. Sci. Rep. 2 (1), 541.
URL http://www.nature.com/articles/srep00541
BCBS, 2006. International convergence of capital measurement and capital standards: a revised framework. Tech. rep., Basel Committee on Banking Supervision.
Beck, R., Jakubik, P., Piloiu, A., 2015. Key Determinants of Non-performing Loans: New Evidence from a Global Sample. Open Econ. Rev. 26 (3), 525–550.
Ben Naceur, S., Marton, K., Roulet, C., 2018. Basel III and bank-lending: Evidence from the United States and Europe. J. Financ. Stab. 39, 1–27.
Berg, M., Hartley, B., Richters, O., 2015. A stock-flow consistent input-output model with applications to energy price shocks, interest rates, and heat emissions. New J. Phys. 17 (1), 15011.
URL http://dx.doi.org/10.1088/1367-2630/17/1/015011
BIS, 2011. Basel III: a Global Regulatory Framework for More Resilient Banks and Banking Systems. Tech. rep., Bank of International Settlements.
Bordalo, P., Gennaioli, N., Shleifer, A., 2018. Diagnostic Expectations and Credit Cycles. J. Finance LXXIII (1).
Borio, C., 2014. The financial cycle and macroeconomics : What have we learnt ? J. Bank. Financ. 45, 182–198.
URL http://dx.doi.org/10.1016/j.jbankfin.2013.07.031
Bovari, E., Giraud, G., Mc Isaac, F., 2018. Coping With Collapse: A Stock-Flow Consistent Monetary Macrody-

namics of Global Warming. Ecol. Econ. 147, 383–398.
Burke, M., Davis, M., Diffenbaugh, N. S., 2018. Large potential reduction in economic damages under UN mitigation targets. Nature Letter.
Caldecott, B., 2018. Stranded assets and the environment: risk, resilience, and opportunity. Routledge, London.
Caldecott, B., McDaniels, J., 2014. Stranded generation assets : Implications for European capacity mechanisms , energy markets and climate policy. Working Paper January 2014, Smith School of Enterprise and the Environment, University of Oxford.
Campiglio, E., Dafermos, Y., Monnin, P., Ryan-Collins, J., Schotten, G., Tanaka, M., 2018. Climate change challenges for central banks and financial regulators. Nat. Clim. Chang. 8, 462–468.
Carney, M., 2015. Resolving the climate paradox: Speech given by Governor of the Bank of England Chair of the Financial Stability Board. Arthur Burn. Meml. Lect. (September), 1–15.
URL https://www.fsb.org/wp-content/uploads/Resolving-the-climate-paradox.pdf
Carol, A., 2001. Market models: a guide to financial data analysis. John Wiley & Sons, Chichester.
CISL, 2015. Unhedgeable risk: How climate change sentiment impacts investment. Tech. rep., University of Cambridge Institute for Sustainability Leadership.
Ciuffo, B., Rosenbaum, E., 2015. Comparative numerical analysis of two stock-flow consistent post-Keynesian growth models. Eur. J. Econ. Econ. Policies Interv. 12 (1), 113–134.
Clements, M. P., Franses, P. H., Swanson, N. R., 2004. Forecasting economic and financial time-series with non-linear models. Int. J. Forecast. 20 (2), 169–183.
CPI, 2019. Global Landscape of Climate Finance 2019. Tech. Rep. November, Climate Policy Initiative, London.
URL https://climatepolicyinitiative.org/publication/global-climate-finance-2019/
Dafermos, Y., Nikolaidi, M., 2018. An assessment of green differentiated capital requirements. Unpubl. Work. Pap. September, 1–41.
Dafermos, Y., Nikolaidi, M., 2019a. Dynamic Ecosystem-FINance-Economy (DEFINE) model , technical description and data, version 1 .1.
URL https://definemodel.files.wordpress.com/2019/08/define-1.1-technical-description-and-data.pdf
Dafermos, Y., Nikolaidi, M., 2019b. Fiscal Policy and Ecological Sustainability: A Post-Keynesian Perspective. In: Arestis, P., Sawyer, M. (Eds.), Front. Heterodox Macroecon. Int. Pap. Polit. Econ. Palgrave Macmillan, Cham, Switzerland, pp. 277–322.
Dafermos, Y., Nikolaidi, M., Galanis, G., 2018a. Can Green Quantitative Easing (QE) Reduce Global Warming ? Policy Br. - Greenwich Polit. Econ. Res. Cent. July, 1–6.
Dafermos, Y., Nikolaidi, M., Galanis, G., 2018b. Climate Change, Financial Stability and Monetary Policy. Ecol. Econ. 152 (May), 219–234.
Dantas, T. M., Cyrino Oliveira, F. L., 2018. Improving time series forecasting: An approach combining bootstrap aggregation, clusters and exponential smoothing. Int. J. Forecast. 34 (4), 748–761.
Delis, M., de Greiff, K., Ongena, S., 2019. Being Stranded on the Carbon Bubble? Climate Policy Risk and the Pricing of Bank Loans. Swiss Financ. Inst. Res. Pap. Ser. 18-19.
Dell'Ariccia, G., 2001. Asymmetric information and the structure of the banking industry. Eur. Econ. Rev. 45 (10), 1957–1980.
Dergiades, T., Tsoulfidis, L., 2007. A new method for the estimation of capacity utilization: Theory and empirical evidence from 14 EU countries. Bull. Econ. Res. 59 (4), 361–381.
Deutsche Bundesbank, 2017. Mark-ups of firms in selected European countries. Mon. Rep. (December), 53–67.
URL https://www.bundesbank.de/Redaktion/EN/Downloads/Publications/Monthly{_}Report{_}Articles/2017/2017{_}12{_}markups.pdf?{_}{_}blob=publicationFile
Dhruba, P., 2018. Managing Credit Risk and improving Access to Finance in Green Energy Projects. ADBI Work. Pap. Ser. 855, 1–21.
URL https://www.adb.org/sites/default/files/publication/437911/adbi-wp855.pdf
Dombret, A., Le Lorier, A., 2017. These are the risks and opportunities of green finance.
URL https://www.weforum.org/agenda/2017/07/green-finance-risk-and-opportunity/
Dombrovskis, V., 2018. Speech by Vice-President Dombrovskis at the High-Level Conference on Financing Sustainable Growth.
URL http://europa.eu/rapid/press-release{_}SPEECH-18-2421{_}en.htm
Dos Santos, C. H., Zezza, G., 2008. A Simplified, Benchmark', Stock-Flow Consistent Post-Keynesian Growth Model. Metroeconomica 59 (3), 441–478.
URL http://doi.wiley.com/10.1111/j.1467-999X.2008.00316.x

Drehmann, M., Juselius, M., Santos, M., 2015. How much income is used for debt payments? A new database for debt service ratios. BIS Q. Rev. (September), 89–103.
ECB, 2007. Box 5: Capacity Utilisation in the Euro Area: Measures and Implications. ECB Mon. Bull. October.
ECB, 2010. Box 4: The recovery of production capacity utilisation in the Euro area. ECB Mon. Bull. October.
ECB, 2019. Update on economic and monetary developments. ECB Econ. Bull. 01.
URL https://www.ecb.europa.eu/pub/economic-bulletin/html/eb201901{~}a3afea780e.en.html{#}IDofOverviewes{_}Eb
Engle, R., 2002. Dynamic conditional correlation: A simple class of multivariate generalized autoregressive conditional heteroskedasticity models. J. Bus. Econ. Stat. 20 (3), 339–350.
Engle, R. F., 2016. Dynamic conditional beta. J. Financ. Econom. 14 (4), 643–667.
Engle, R. F., Bollerslev, T., 1986. Modelling the persistence of conditional variances. Econom. Rev. 5 (1), 1–50.
Engle, R. F., Focardi, S. M., Fabozzi, F. J., 2012. ARCH / GARCH Models in Applied Financial Econometrics. Financ. Econom., 689–701.
URL http://onlinelibrary.wiley.com/doi/10.1002/9780470404324.hof003060/abstract
ESRB, ECB, 2019. ESRB Risk Dashboard September 2019. Tech. Rep. September, European Systemic Risk Board & European Central Bank.
European Commission, 2008. Sustainable Consumption and Production and Sustainable Industrial Policy Action Plan.
European Commission, 2010. Europe 2020 - A strategy for smart, sustainable and inclusive growth.
URL https://ec.europa.eu/eu2020/pdf/COMPLETENBARROSO007-Europe2020-ENversion.pdf
European Commission, 2014. A policy framework for climate and energy in the period from 2020 to 2030.
URL https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX{%}3A52014DC0015
European Commission, 2018. REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL: establishing a Programme for the Environment and Climate Action (LIFE) and repealing Regulation (EU) No 1293/2013.
European Commission, 2019. Taxation trends in the European Union. Tech. rep., DG Taxation and Customs Union.
URL http://ec.europa.eu/taxation{_}customs/taxation/gen{_}info/economic{_}analysis/tax{_}structures/index{_}en.htm
Eurostat, 2019a. Current level of capacity utilization in manufacturing industry.
URL https://ec.europa.eu/eurostat/tgm/table.do?tab=table{&}init=1{&}language=en{&}pcode=teibs070{&}plugin=1
Eurostat, 2019b. Eurostat Statistical Database.
URL http://ec.europa.eu/eurostat/
EY, 2018. Worldwide Capital and Fixed Assets Guide 2018. Tech. rep., EY.
Financial Times, 2015. European payouts rise by more than 10%.
URL https://www.ft.com/content/d2c1aa4a-d605-11e4-b3e7-00144feab7de
Fratzscher, M., König, P. J., Lambert, C., 2016. Credit provision and banking stability after the Great Financial Crisis: The role of bank regulation and the quality of governance. J. Int. Money Financ. 66, 113–135.
FRED Economic Data, 2019. Business Tendency Surveys for Manufacturing: Capacity Utilization: Rate of Capacity Utilization: European Commission and National Indicators for Germany.
URL https://fred.stlouisfed.org/series/BSCURT02DEQ160S
Galuscak, K., Horvath, R., 2018. Challenges for financial stability in Europe. J. Financ. Stab. 36, 263–264.
Ghosh, A., 2015. Banking-industry specific and regional economic determinants of non-performing loans : Evidence from US states. J. Financ. Stab. 20, 93–104.
Godley, W., Lavoie, M., 2012. Monetary Economics: An Integrated Approach to Credit, Money, Income, Production and Wealth., 2nd Edition. Palgrave Macmillan, New York.
Görzig, B., 2007. Depreciation in EU member states: empirical and methodological differences. EU KLEMS Work. Pap., 1–29.
URL http://euklems.net/pub/no17.pdf
Greenwood, B. J., Hercowitz, Z., Huffman, G. W., 1988. Investment , Capacity Utilization , and the Real Business Cycle. Am. Econ. Rev. 78 (3), 402–417.
Greenwood, R., Hanson, S. G., Jin, L. J., 2016. A model of credit market sentiment. Unpubl. Work. Pap. Harvard Univ.
Greenwood, R., Shleifer, A., 2014. Expectations of returns and expected returns. Rev. Financ. Stud. 27 (3), 714–746.
Hassler, J., Krusell, P., Smith, A. A., 2016. Environmental Macroeconomics. In: Taylor, J. B., Uhlig, H. (Eds.), Handb. Macroecon. Vol. 2. Elsevier, Amsterdam, The Netherlands, Ch. 24, pp. 1893–2008.

HLEG, 2018. Financing a Sustainable European Economy. Tech. rep., EU High-Level Expert Group on Sustainable Finance.

ILO, OECD, 2015. The Labour Share in G20 Economies. Tech. Rep. February, International Labour Organization & Organization for Economic Cooperation and Development.

IMF, 2019. Fiscal Monitor: How to Mitigate Climate Change. Tech. rep., International Monetary Fund, Washington, D.C.

IPCC, 2014. Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Tech. rep., Intergovernmental Panel on Climate Change.

IPCC, 2018. Global Warming of 1.5C - Summary for Policymakers. Tech. rep., Intergovernmental Panel on Climate Change.

Jakubik, P., Reininger, T., 2013. Determinants of non-performing loans in Central and Eastern European countries. Focus Eur. Econ. Integr. Q3, 48–66.

Juselius, M., Drehmann, M., 2015. Leverage dynamics and the real burden of debt. BIS Work. Pap. (501).
URL https://www.bis.org/publ/work501.htm

Kaminsky, G. L., Reinhart, C. M., 1999. The Twin Crises : The Causes of Banking and Balance-Of-Payments Problems. Am. Econ. Rev. 89 (3), 473–500.

King, M. R., 2010. Mapping Capital and Liquidity Requirements to Bank Lending Spreads. BIS Work. Pap. 324.

Klein, N., 2013. Non-Performing Loans in CESEE: Determinants and Impact on Macroeconomic Performance. IMF Work. Pap. 13 (72), 1.

Krogstrup, S., Oman, W., 2019. Macroeconomic and Financial Policies for Climate Change Mitigation: A Review of the Literature. IMF Work. Pap. 19 (185), 1–58.

Lavoie, M., 2014. Post-Keynesian Economics: New Foundations. Edward Elgar Publishing, Cheltenham, UK.

Lazard, 2018. Lazard's levelized cost of energy analysis - version 12.0. Tech. Rep. November, Lazard.
URL https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2018/

Lopez-Salido, D., Stein, J. C., Zakrajsek, E., 2017. Credit-Market Sentiment and the Business Cycle. Q. J. Econ. 132 (3), 1373–1426.

Martynova, N., 2015. Effect of Bank Capital Requirements on Economic Growth: A Survey. Ned. Bank Work. Pap. NO. 467/March 2015 (467), 1–25.

Mazzucato, M., Penna, C. C., 2016. Beyond market failures: the market creating and shaping roles of state investment banks. J. Econ. Policy Reform 19 (4), 305–326.
URL http://dx.doi.org/10.1080/17487870.2016.1216416

McCombie, J., 2002. Increasing Returns and the Verdoorn Law from a Kaldorian Perspective. In: McCombie, J., Pugno, M., Soro, B. (Eds.), Product. growth Econ. Perform. Essays Verdoorn's Law. Palgrave Macmillan, Basingstoke, pp. 64–114.

McLeay, M., Radia, A., Thomas, R., 2014. Money Creation in the Modern Economy. Bank Engl. Q. Bull. (Q1), 1–14.

Mercure, J. F., Pollitt, H., Viñuales, J. E., Edwards, N. R., Holden, P. B., Chewpreecha, U., Salas, P., Sognnaes, I., Lam, A., Knobloch, F., 2018. Macroeconomic impact of stranded fossil fuel assets. Nat. Clim. Chang. 8 (7), 588–593.
URL http://dx.doi.org/10.1038/s41558-018-0182-1

Metcalf, G., Weisbach, D., 2013. Carbon Taxes. Encycl. Energy, Nat. Resour. Environ. Econ. 1, 9–14.

Minsky, H. P., 1977. The Financial Instability Hypothesis : An Interpretation of Keynes and an Alternative to " Standard " Theory. Nebraska J. Econ. Bus. 16 (1), 5–16.

Monasterolo, I., 2020. Climate Change and the Financial System. Annu. Rev. Environ. Resour. 12 (Forthcoming).

Monasterolo, I., Battiston, S., Janetos, A. C., Zheng, Z., 2017. Vulnerable yet relevant: the two dimensions of climate-related financial disclosure. Clim. Change 145 (3-4), 495–507.

Monasterolo, I., de Angelis, L., 2020. Blind to carbon risk? An analysis of stock market reaction to the Paris Agreement. Ecol. Econ. 170 (106571).
URL https://doi.org/10.1016/j.ecolecon.2019.106571

Monasterolo, I., Raberto, M., 2017. Is there a role for Central Banks in the low-carbon transition? A Stock-Flow Consistent modelling approach. SSRN Work. Pap. November, 1–32.

Monasterolo, I., Raberto, M., 2018. The EIRIN Flow-of-funds Behavioural Model of Green Fiscal Policies and Green Sovereign Bonds. Ecol. Econ. 144, 228–243.
URL http://dx.doi.org/10.1016/j.ecolecon.2017.07.029

Monasterolo, I., Raberto, M., 2019. The impact of phasing out fossil fuel subsidies on the low-carbon transition. Energy Policy 124, 355–370.

Morana, C., Sbrana, G., 2018. Some financial implications of global warming: An empirical assessment. Fond. Eni

Enrico Mattei Work. Pap. 001.2018, 1–55.
URL https://ssrn.com/abstract=3092970
Myers, S. C., 1984. The Capital Structure Puzzle. J. Finance 39 (3), 575–592.
Naqvi, A., Stockhammer, E., 2018. Directed Technological Change in a Post-Keynesian Ecological Macromodel. Ecol. Econ. 154 (June), 168–188.
NGFS, 2019. A call for action - Climate change as a source of financial risk. Tech. Rep. April, Network for Greening the Financial System.
URL https://www.ngfs.net/sites/default/files/medias/documents/ngfs{_}first{_}comprehensive{_}report{_}-{_}1704 pdf
Nick Robins, McDaniels, J., 2016. Greening the Banking System: Taking Stock of G20 Green Banking Market Practice. UNEP Inq. Work. Pap. 16 (12).
Nikiforos, M., Zezza, G., 2017. Stock-Flow Consistent Macroeconomic Models: a Survey. J. Econ. Surv. 31 (5), 1204–1239.
Nkusu, M., 2011. Nonperforming Loans and Macrofinancial Vulnerabilities in Advanced Economies. IMF Work. Pap. 11 (161), 1.
Nordhaus, W. D., 1993. Rolling the DICE: An optimal transition path for controlling greenhouse gases. Resour. Energy Econ. 15, 27–50.
Nordhaus, W. D., 2017. Revisiting the social cost of carbon. Proc. Natl. Acad. Sci. U. S. A. 114 (7), 1518–1523.
OECD, 2018. Effective Carbon Rates 2018 - Pricing Carbon Emissions Through Taxes and Emissions Trading. Tech. rep., OECD.
URL https://www.oecd.org/tax/effective-carbon-rates-2018-9789264305304-en.htm
Official Journal of the European Union, 2009. DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.
Official Journal of the European Union, 2013. DECISION No 1386/2013/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 20 November 2013 on on a General Union Environment Action Programme to 2020 Living well, within the limits of our planet'.
Pérez Montes, C., Trucharte Artigas, C., Cristófoli, M. E., Lavín San Segundo, N., 2016. The impact of the IRB approach on the risk weights of European banks. J. Financ. Stab. 39, 147–166.
Pigou, A. C., 1920. The economics of welfare. Macmillan & Co., London.
Pindyck, R. S., 2013. Climate Change Policy: What Do the Models Tell Us? J. Econ. Lit. 51 (3), 860–872.
URL http://pubs.aeaweb.org/doi/10.1257/jel.51.3.860
Ploeg, F. V. D., Rezai, A., 2019. Simple Rules for Climate Policy and Integrated Assessment. Environ. Resour. Econ. 72 (1), 77–108.
URL https://doi.org/10.1007/s10640-018-0280-6
Ponta, L., Raberto, M., Teglio, A., Cincotti, S., 2018. An Agent-based Stock-flow Consistent Model of the Sustainable Transition in the Energy Sector. Ecol. Econ. 145, 274–300.
URL https://doi.org/10.1016/j.ecolecon.2017.08.022
Popp, D., Newell, R. G., Jaffe, A. B., 2010. Energy, the environment, and technological change. In: Hall, B., Rosenberg, N. (Eds.), Handb. Econ. Innov. Vol. 2. Elsevier B.V., Amsterdam, The Netherlands, Ch. 21, pp. 873–937.
URL http://dx.doi.org/10.1016/S0169-7218(10)02005-8
Rausch, S., Metcalf, G. E., Reilly, J. M., 2011. Distributional impacts of carbon pricing: A general equilibrium approach with micro-data for households. Energy Econ. 33 (1), 20–33.
Romer, P. M., 1990. Endogenous Technological Change. J. Polit. Econ. 98 (S5), S71.
Schoenmaker, D., 2019. Greening Monetary Policy. SSRN Electron. J., 1–26.
Schularick, M., Taylor, A. M., 2012. Credit Booms Gone Bust: Monetary Polict, Leverage Cycles & Financial Crisis, 1870-2008. Am. Econ. Rev. 102 (2), 1029–1061.
Silva, W., Kimura, H., Sobreiro, V. A., 2017. An analysis of the literature on systemic financial risk: A survey. J. Financ. Stab. 28, 91–114.
URL http://dx.doi.org/10.1016/j.jfs.2016.12.004
Stern, N., 2013. The Structure of Economic Modeling of the Potential Impacts of Climate Change: Grafting Gross Underestimation of Risk onto Already Narrow Science Models. J. Econ. Lit. 51 (3), 838–859.
URL http://pubs.aeaweb.org/doi/abs/10.1257/jel.51.3.838
Stiglitz, J., Stern, N., Duan, M., Edenhofer, O., Giraud, G., Heal, G., Lèbre la Rovere, E., Morris, A., Moyer, E., Pangestu, M., Shukla, P., Sokona, Y., Winkler, H., 2017. Report of the High-Level Commission on Carbon Prices.

Tech. rep., Carbon Pricing Leadership Coalition.
Stiglitz, J. E., 2019. Addressing climate change through price and non-price interventions. Eur. Econ. Rev.
URL https://doi.org/10.1016/j.euroecorev.2019.05.007
Stolbova, V., Monasterolo, I., Battiston, S., 2018. A Financial Macro-Network Approach to Climate Policy Evaluation. Ecol. Econ. 149 (March), 239–253.
Taylor, A. M., 2015. Credit, Financial Stability, and the Macroeconomy. Annu. Rev. Econom. 7, 309–341.
Thomä, J., Hilke, A., 2018. The green supporting factor - Quantifying the impact on European banks and green finance. Tech. rep., 2degree investing initiative.
Timmermann, A., 2018. Forecasting Methods in Finance. Annu. Rev. Financ. Econ. 10 (1), 449–479.
Tobin, J., 1982. Money and Finance in the Macroeconomic Process. J. Money, Credit Bank. 14 (2), 171–204.
Trucost, ESG Analysis, 2018. Connecting the dots : Energy transition scenarios and credit quality. Tech. rep., Trucost, ESG Analysis.
UNEP-FI, 2018. Making Waves - Aligning the Financial System with Sustainable Development. Tech. Rep. April, United Nations Environment Programme.
UNFCCC, 2015. Paris Agreement.
Volz, U., Böhnke, J., Eidt, V., Knierim, L., Richert, K., Roeber, G.-M., 2015. Financing the Green Transformation: How to make Green Finance work in Indonesia. Palgrave Macmillan, Hampshire, UK.
Weitzman, M. L., 2014. Fat tails and the social cost of carbon. Am. Econ. Rev. 104 (5), 544–546.
World Bank, 2019. Fiscal Policies for Development and Climate Action. Tech. rep., The World Bank Group.
URL http://documents.worldbank.org/curated/en/340601545406276579/pdf/133156-REPLACEMNET-PUBLIC.pdf
Zachmann, G., Fredriksson, G., Claeys, G., 2018. The distributional effects of climate policies. Tech. rep., Bruegel Blueprint Series.
Zuckerman, J., Frejova, J., Granoff, I., Nelson, D., 2016. Investing at Least a Trillion Dollars a Year in Clean Energy. Tech. rep., New Climate Economy, London and Washington, DC.
URL http://newclimateeconomy.report/misc/working-papers

Appendix A. Balance Sheet and the Transaction Flow Matrix

Table A.2: Balance Sheet of the Economy

	Households (H)	**Cons. Firms** (F)	**Brown cap.** (B)	**Green cap.** (G)	**Govt.** (Gov)	**Banks** (Bk)	$\sum$
Capital Stock		$+K_t^F$	$+K_t^B$	$+K_t^G$	$+K_t^{Gov}$		$+K_t$
Deposits	$+V_t^H$	$+V_t^F$	$+V_t^B$	$+V_t^G$		$-V_t$	0
Government Bonds					$-GBond_t$	$+GBond_t$	0
Loans		$-L_t^F$	$-L_t^B$	$-L_t^G$		$+L_t$	0
Non-performing Loans		$+NPL_t^F$	$+NPL_t^B$	$+NPL_t^G$		$-NPL_t$	0
Bank Equity	$+E_t^{Bk}$					$-E_t^{Bk}$	
Balance Net Worth	$-NW_t^H$	$-NW_t^F$	$-NW_t^B$	$-NW_t^G$	$-NW_t^{Gov}$	$-NW_t^{Bk}$	$-NW_t$
$\sum$	0	0	0	0	0	0	0

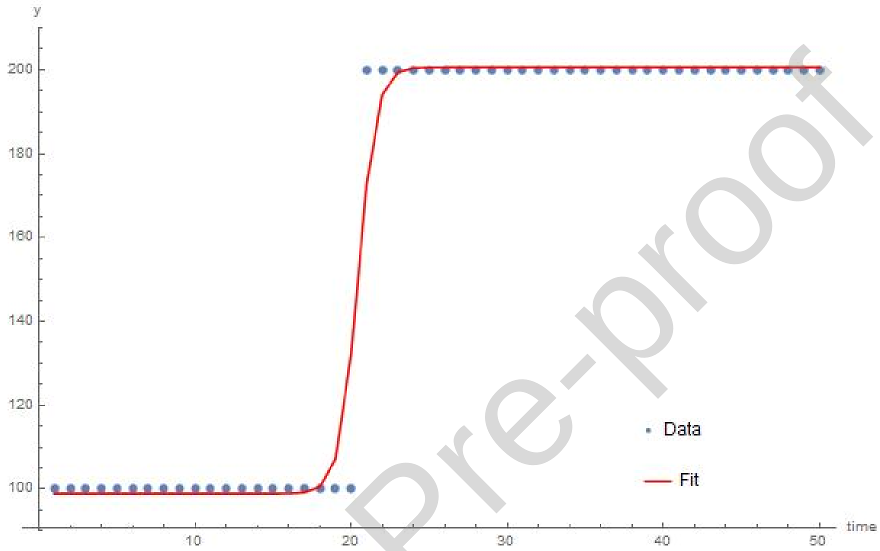
Table A.3: Transaction Flow Matrix

		Firm Sector									
	Households (H)	**Consumption Good** (F)		**Brown Capital** (B)		**Green Capital** (G)		**Govt.** (Gov)	**Banks** (Bk)		$\sum$
		Current	Capital	Current	Capital	Current	Capital		Current	Capital	
Consumption	$-C_t^H$	$+C_t^H$									0
Govt. Exp.		$+C_t^{Gov}$						$-C_t^{Gov}$			0
Investment			$-I_t^F$	$+I_t^B+\phi_t^B(I_t^F+I_t^{Gov})$	$-I_t^B$	$+I_t^G+(1-\phi_t^B)(I_t^F+I_t^{Gov})$	$-I_t^G$	$-I_t^{Gov}$			0
Wages	$+WB_t$	$-WB_t^F$		$-WB_t^B$		$-WB_t^G$					0
Profits	$+Div_t$	$-\Pi_t^F$	$+RE_t^F$	$-\Pi_t^B$	$+RE_t^B$	$-\Pi_t^G$	$+RE_t^G$		$-\Pi_t^{Bk}$	$+RE_t^{\mathbf{Bk}}$	0
Loan Repay		$-\rho L_{t-1}^F$	$+\rho L_{t-1}^F$	$-\rho L_{t-1}^B$	$+\rho L_{t-1}^B$	$-\rho L_{t-1}^G$	$+\rho L_{t-1}^G$				0
Taxes	$-T_t^H$	$-T_t^F$		$-T_t^B$		$-T_t^G$		$+T_t$			0
i Loans		$-r_t^F(L_{t-1}^F-NPL_{t-1}^F)$		$-r_t^B(L_{t-1}^B-NPL_{t-1}^B)$		$-r_t^G(L_{t-1}^G-NPL_{t-1}^G)$			$+r(L_{t-1}+NPL_{t-1})$		0
i Deposits	$+r^V V_{t-1}^H$	$+r^V V_{t-1}^F$		$+r^V V_{t-1}^B$		$+r^V V_{t-1}^G$			$-r^V V_{t-1}^i$		0
i Gov. Bonds								$-r^{Gov}GBond_{t-1}$	$+r^{Gov}GBond_{t-1}$		0
ΔLoans			$+\Delta L_t^F$		$+\Delta L_t^B$		$+\Delta L_t^G$			$-\Delta L_t$	0
ΔNPL			$-\Delta NPL_t^F$		$-\Delta NPL_t^B$		$-\Delta NPL_t^G$			$+\Delta NPL_t$	0
ΔDeposits	$-\Delta V_t^H$		$-\Delta V_t^F$		$-\Delta V_t^B$		$-\Delta V_t^G$			$+\Delta V_t$	0
ΔGov. Bonds								$+\Delta GBond_t$		$-\Delta GBond_t$	0
ΔBank Equity	$+\Delta E_t^{Bk}$									$-\Delta E_t^{Bk}$	0
$\sum$	0	0	0	0	0	0	0	0	0	0	0

Appendix B. Climate sentiments module: An illustrated example

In this section we illustrate the process defined in Section 3 on climate sentiments with an example. We generate a data series $\mathbf{\Omega}$ as shown in Figure B.1. The y-axis value is 100 for the first 20 time periods. This value jumps to 200 at time period 21 and stays constant till the 50^{th} time period.

Figure B.1: Sample data and fitted curve



If we know this data series in advance, we can clearly see that a logistic function fits this data very well. This is indeed the case as we see the fitted curve in Figure B.1.

$$\hat{\mathbf{\Omega}} = f(\boldsymbol{\beta}) \tag{B.1}$$

$$\hat{\mathbf{\Omega}} = \beta_1 + \frac{\beta_2 - \beta_1}{1 + \beta_3 e^{-\beta_4 x}} \tag{B.2}$$

$$\hat{\mathbf{\Omega}} = 98.91 + \frac{101.74}{1 + 1.32 \times 10^{15} e^{-1.70x}} \tag{B.3}$$

We use the generic logistic functional form shown in Equation B.2 defined by the parameter space $\boldsymbol{\beta} = \{\beta_1, \beta_2, \beta_3, \beta_4\}$. The derived fitted functional form is defined in Equation B.3.

Suppose that instead of observing the complete data series, we are at time step 6, where we know the first $a = 5$ periods and need to make a prediction about the next $b = 5$ periods. Since the first 5 periods form a straight line, the predicted values for the next 5 periods will also be a straight line. But, if we do the same exercise at time period 18, 2 steps before the series jump, we would still get a straight line for the next 5 time periods if we only observe the past 5 time periods. This completely misestimates the impact at time step 21 when the series jumps.

In order to build in climate sentiments, such that we know that at time period 21 a policy will come into effect that doubles the value of $\hat{\mathbf{\Omega}}$, we can still predict the normal series using the values of the past 5 time periods which would be $\mathbf{\Omega} = \{100, 100, 100, 100, 100\}$. The projected values would be $\hat{\mathbf{\Omega}} = \{100, 100, 100, 100, 100\}$. This is done by forcing a logistic function to fit to this data, which recovers the following functional form:

$$\hat{\mathbf{\Omega}} = 100 + \frac{2.842 \times 10^{-14}}{1 + 0.709e^{-1.934x}} \tag{B.4}$$

If we are aware of the policy implementation at time period $t + v = 21$ that increases the values of $\mathbf{\Omega}$ by 100%, or $1 + \zeta = 2$, then we can define a vector that can incorporate this information. Since we are at time step 18, and predicted the next 5 values, the individual entries would be $\boldsymbol{Z} = \{1, 1, 2, 2, 2\}$. or $z_i = 1$ if $i < 21$ and $1 + \zeta = 2$ if $i \geq 21$. The modified predicted series $\hat{\mathbf{\Omega}}^* = \hat{\mathbf{\Omega}}.\boldsymbol{Z} = \{100, 100, 200, 200, 200\}$.

Since we have modified the predicted series, we need to refit the data to generate a point estimate for the next time period $t = 19$. This allows us to combine the original and modified predicted series to *smooth out* the discrete jump occurring from modifying the predicted series. The combined series $\tilde{\mathbf{\Omega}}^* = [\mathbf{\Omega}, \hat{\mathbf{\Omega}}^*] = \{100, 100, 100, 100, 100, 100, 100, 100, 200, 200, 200\}$ represents time steps $\{t-b, \ldots, t, t+1, \ldots, t+v, \ldots, t+b\} = \{14, \ldots, 23\}$, where $t = 18, a = 5, b = 5, v = 3$. The refitted logistics function equals

$$\hat{\tilde{\mathbf{\Omega}}}^* = f(\boldsymbol{\beta}) \tag{B.5}$$

$$\hat{\tilde{\mathbf{\Omega}}}^* = \beta_1 + \frac{\beta_2 - \beta_1}{1 + \beta_3 e^{-\beta_4 x}} \tag{B.6}$$

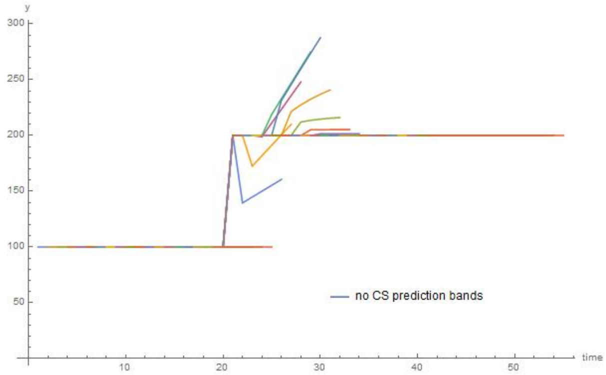
$$\hat{\tilde{\mathbf{\Omega}}}^* = (-2.109 \times 10^6) + \frac{2.11 \times 10^6}{1 + 0.00152e^{-0.0118x}} \tag{B.7}$$

From this series, the point estimate from time period $t + 1 = 19$ equals $\hat{\tilde{\Omega}}^*_{24} = 110.081$.

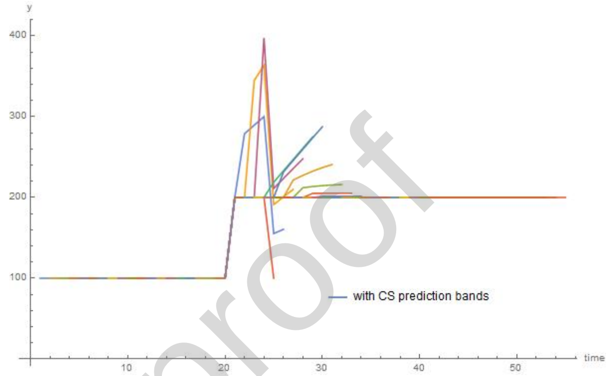
Since we have a rolling time series where past values change as the time step increases, we effectively estimate $T - a$ models, where $T = 50$ is the last time step, and $a = 5$ is the past observations we need to have in order to initiate the predictions. Figure B.2 shows the different models with and without climate sentiments. The prediction fits of the micro series are shown in different color bands. Figure B.2 highlights that with climate sentiments, the series adjusts in advance to the jump. In contrast without climate sentiments, the series fails to accounts for future changes in the values, effectively showing a linear prediction around the time periods where the series spike.

The refitted series are used to generate the point estimates for time periods $t + 1$. These predicted points are shown in Figure B.3 with and without climate sentiments. As shown in Figure B.3, if one accounts for future changes in policies, the transition processes can be initiated earlier. Without climate sentiments, the adjustment started after the policy is implemented resulting in a high spike in predicted values can be further increase the volatility in the system.

Figure B.2: Building in sentiments

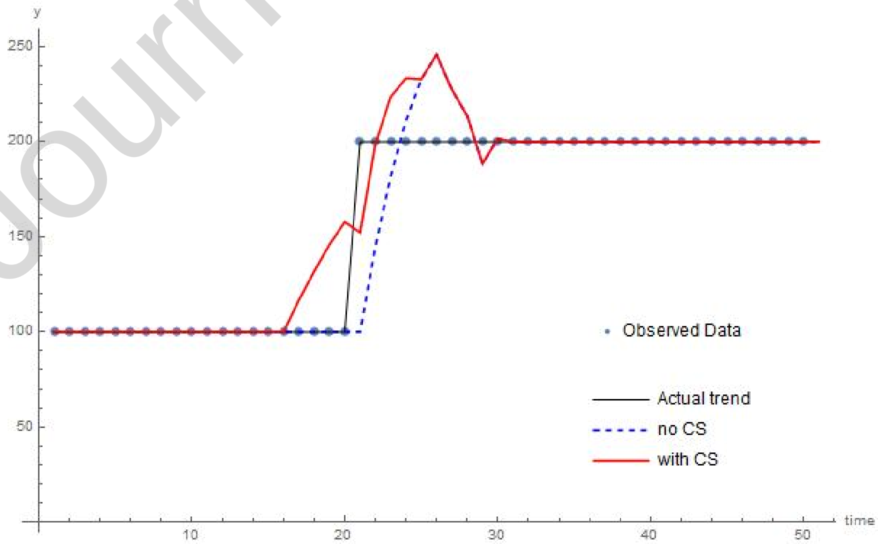


(a) No climate sentiments



(b) With climate sentiments

Figure B.3: Predicted values



Appendix C. Variables and Parameters

Table C.4: Parameters

Parameter	Description	Value	Source
The Firm Sector			
δ	Capital depreciation rate	0.1	Adapted from EY (2018) & Görzig (2007)
γ_i	Investment rate	10%	Selected from a reasonable range of values in the literature
γ_ϵ^B	Brown productivity adjustment	5%	Selected from a reasonable range of values (see Sensitivity analysis E.1 & E.2
γ_ϵ^G	Green productivity adjustment	10%	Selected from a reasonable range of values (see Sensitivity analysis E.1 & E.2
$\bar{u}$	Target capacity utilization rate	80%	EU-28 average between 1980-2019 (Eurostat, 2019b)
ρ	Loan repayment rate	10%	Adapted from ECB (2019) for long-term investment loans
η	Investment share of retained earnings	25%	Calibrated for 60% debt to GDP ratio of Non-financial sector (ESRB and ECB, 2019)
π^X	Share of non-retained earnings	75%	Broadly in line with average dividend payout ratio for Europe in 2015 (Financial Times, 2015)
ω	Wage rate	1	Calibrated to generate a wage share of 65% (OECD long term average (ILO and OECD, 2015))
ϵ^L	Labor productivity	1.25	Calibrated to generate a wage share of 65% (OECD long term average (ILO and OECD, 2015))
θ	Markup costs	10%	Selected from a reasonable range of values in the literature and broadly in line with Deutsche Bundesbank (2017)
τ^n	Profit tax on firms	20%	EU average (European Commission, 2019)
τ^{CT}	Potential carbon tax without climate sentiments	2.6%	Calibrated to achieve 45% green capital share in the end of simulation run
τ^{CT}	Potential carbon tax with climate sentiments	2.25%	Calibrated to achieve 45% green capital share in the end of simulation run
λ_0^B	Autonomous brown capital good demand	0.5	Mid-level elasticity assumed
λ_0^G	Autonomous green capital good demand	0.5	Mid-level elasticity assumed
λ_{11}^B	Elasticity of brown capital good demand to brown capital good prices	-0.5	Mid-level elasticity assumed
λ_{12}^B	Elasticity of brown capital good demand to green capital good prices	0.5	Mid-level elasticity assumed
λ_{13}^B	Elasticity of brown capital good demand to brown capital productivity	0.5	Mid-level elasticity assumed
λ_{14}^B	Elasticity of brown capital good demand to green capital good prices	-0.5	Mid-level elasticity assumed
λ_{21}^G	Elasticity of green capital good demand to brown capital good prices	0.5	Mid-level elasticity assumed
λ_{22}^G	Elasticity of green capital good demand to green capital good prices	-0.5	Mid-level elasticity assumed
λ_{23}^G	Elasticity of green capital good demand to brown capital productivity	-0.5	Mid-level elasticity assumed
λ_{24}^G	Elasticity of green capital good demand to green capital productivity	0.5	Mid-level elasticity assumed

Table C.5: Parameters

Parameter	Description	Value	Source
The Household Sector			
α_1	Propensity to consume out of income	85%	EU average in 2015 (Eurostat, 2019b)
α_2	Propensity to consume out of savings	10%	Adapted from Arrondel et al. (2015)
The Government Sector			
g_1	Revenue dependent government spending	50%	Calibrated to generate 25% government to GDP ratio (excluding social transfers and education spending) (Eurostat, 2019b)
g_2	Revenue dependent government investment	0.1%	Calibrated to generate 25% government to GDP ratio (excluding social transfers and education spending) (Eurostat, 2019b)
r^{Gov}	Interest rate on government bonds	1%	Rounded Euro Area ECB Government Bond 10 Year Yield (ECB 2019)
The Banking Sector			
χ^F	Risk weight consumption good sector	100%	Private sector risk weights (BCBS, 2006)
χ^B	Risk weight brown capital good sector	100%	Private sector risk weights (BCBS, 2006)
χ^G	Risk weight green capital good sector	100%	Private sector risk weights (BCBS, 2006)
χ^{Gov}	Risk weight green capital good sector	0%	Sovereign risk weights (BCBS, 2006)
ν	Reduction of green capital risk weight (GSF scenario)	35%	Calibrated to achieve 45% green capital share in the end of simulation run
CAR^T	Target capital adequacy ratio	8%	Based on Basel III regulatory requirements (BIS, 2011)
$\bar{r}$	Central Bank interest rate	0.02	Rounded average interest rate of ECB between 1999 and 2019 (ECB 2019 Data)
κ_0	Capital adequacy ratio adjustment rate	10%	Selected from a reasonable range of values
κ_1^n	Sectoral interest rate adjustment rate	10%	Selected from a reasonable range of values (see Sensitivity analysis E.1 & E.2)
κ_2^G	GSF interest rate adjustment rate	5%	Selected from a reasonable range of values
$\kappa_2^{B,F}$	CGSF interest rate adjustment rate	0%	

Table C.6: Variable Description

Variable	Description	Equation No.
The Firm Sector		
Y_t, y_t	Nominal, real output	1,3
C_t	Nominal household consumption	1,21,22
I_t, i_t	Nominal, real investment	1,2, 11, 10,9
J_t	Nominal government expenditures	1,24
K_t, k_t	Nominal, real capital stock	4,10,9
N_t	Labor demand	4
ϕ_t	Share of green or brown capital investment	5,25
ϵ_t	Capital productivity	7
u_t	Capacity utilization rate	10
RE_t	Retained earnings	11
Div_t	Dividends	20
L_t	Loan demand	11
NPL_t	Non-performing loans (level)	12,15,32
ξ_t	Non-performing loans ratio	13
WB_t	Wage Bill	14,16,18,20
KB_t	Investment costs	15,16,18
UC_t	Unit costs	16,17
p_t	Sectoral price level	17
Π_t	Sectoral profits	18,32
T_t	Profit Tax	23
The Household Sector		
YD_t	Disposable Income	20,21,22
T_t^H	Household Taxes	23
V_t	Deposits	21,22
The Government Sector		
$GBond_t$	Government Bonds	27
The Banking Sector		
CAR_t	Capital Adequacy Ratio	29,30
S_t	Bank Equity	29
r_t^V	Deposit interest rates	30,32,18
r_t^n	Sector specific interest rate	32,15
$\tilde{\Pi}_t$	Bank's expected sectoral profits	32

Appendix D. Sensitivity analysis

The sensitivity analysis aims to shed more light on model dynamics and the impact of distinct policy parameter values for model outcomes. This is important to understand relative impact strength of different degrees of climate-aligned policies and detect potential non-linearities or qualitative outcome changes. This can provide insights on the extent model results are driven by policy parameter values. As stressed by Ciuffo and Rosenbaum (2015) this should enhance understanding and tractability of more complex models.

Appendix D.1. Change of policy parameters

First, we assess the implications on model outcomes for different policy parameter values and interactions of climate-aligned policies, providing insights on model linearity and effect sizes. We do so by altering the policy parameters, namely the carbon tax, and the GSF. We are also interested in exploring the conditionality of the carbon tax for model outcomes. This means that carbon tax revenues are either redistributed to households or pour into the government's budget as it is the case in the results of the main paper. This leads us to five different climate-aligned policy combinations, namely a non-redistributed carbon tax alone (*CTax*), a green supporting factor alone (*GSF*), a policy mix of non-redistributed carbon tax and green supporting factor (*CTax+GSF*), a redistributed carbon tax (*CTax+Dis*) and finally a combination of a redistributed carbon tax and a green supporting factor (*All*). We compare end of scenario run values of the different climate-aligned policy scenarios with altered policy parameters to the business as usual (BAU) case of no climate-aligned policy scenario. All other scenario runs are indexed to the BAU.

Table D.7 shows the different climate-aligned policy parameter values ranging from 0% to 10% of profits for the carbon tax and from 100% (no *GSF*) to 0% (zero-risk weight for green loans) for the *GSF* with step sizes of 2.5% and 10%, respectively. As indicated above, the carbon tax could then be either redistributed to households or pour into the government budget (redistribution Yes/No). In total this gives us 60 observation points for each variable, allowing us more insights on model dynamics.

The boxplots show the range of model outcomes from the lowest to the highest variable value for the different parameter alterations and policy combinations. In the baseline sensitivity version (red bars) we assume no climate sentiments of the banking sector.

Table D.7: Climate policy parameter range

Policy parameter	Parameter range	Stepsize	Value applied in paper	Carbon tax redistribution
Carbon tax (τ^{CT})	0% – 10%	2.5%	2.6%	Yes/No
Green supporting factor (χ^{G})	100% – 0%	10%	62.5%	No

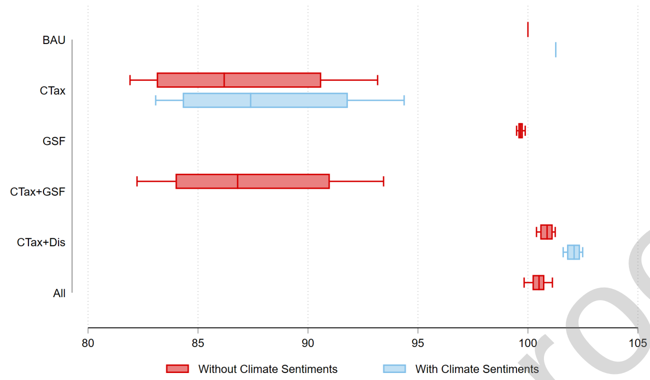
To check the impact of climate sentiments, we test the carbon tax impact in the redistribution and non-redistribution case for both with or without the banking sector having climate sentiments. In case of climate sentiments, the banking sector forms expectation about a carbon tax and its implications on firms' profits thus granting more favorable/unfavorable interest rates for the different sectors (blue bars).

Figure D.1a shows the impact of different policy parameters and policy combinations on real GDP y. As we can see, the BAU scenario with no climate sentiments (red bar) represents 100 in that graph and all other policy scenarios are indexed against the BAU. As becomes clear from that graph, a carbon tax alone ($CTax$) is generally detrimental for GDP, with values ranging from 93 for a carbon tax of 2.5% to 82 for a carbon tax of 10%. For an analysis of the direction of change, that is the higher the policy parameter the higher/lower the core variable, please have a look at the heatmaps in part Appendix D.2. Climate sentiments play out in having less detrimental GDP effects because the bank adjusts credit conditions earlier, leading to green capital productivity increases and a higher green capital share at the time of the policy implementation. The GSF alone is almost neutral with regard to GDP, supporting the result from above that the GSF has higher implications for the banking sector and credit market. In combination with the carbon tax ($CTax+GSF$) GDP impacts are slightly lower compared to the carbon tax alone ($CTax$) indicating the positive effect on green vs. brown productivity (Fig. D.2b) with that policy combination. Interestingly, the detrimental effects of the carbon tax are reversed when revenues are redistributed, indicating the strong role of demand for GDP in the model. Finally, a combination of the two policies with redistribution (*All*) is also positive compared to the (BAU), though the GSF seems to dampen positive effects for GDP slightly. This could be potentially a result of lower banking sector's profits due to the low interest rates for the green capital goods sector on top of making brown capital goods more expensive (Fig. D.4c).

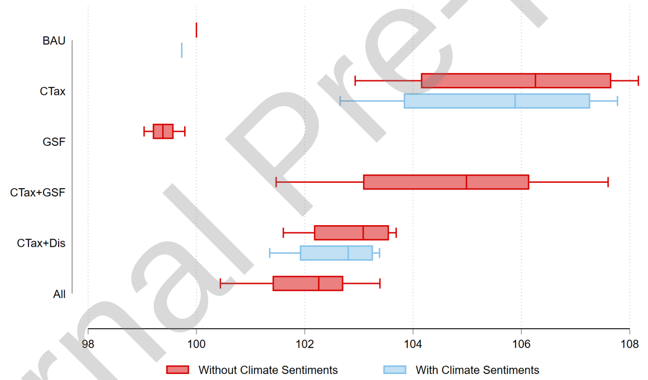
Consumption good prices (Fig. D.1b) work the same way as in the main paper, with the carbon tax (with its different policy combinations) generally making consumption goods more expensive. The GSF in turn has an overall smaller effect since it reduces consumption good prices by lowering interest rates and thus unit costs for the green capital goods sector. Climate sentiments in the banking sector result in lower price increases due to productivity gains in the green sector induced by lower interest rates already before the carbon tax has been implemented. Redistribution plays out positively since it fosters further productivity improvements of green capital as a result of high investment demand. The higher demand makes green capital even more competitive resulting in lower consumption goods price increases.

For relative capital good prices of green versus brown (Fig. D.1c), we observe that the carbon tax has a stronger effect on the relative price than the GSF. The carbon tax works by making the brown capital good more expensive and thus directly affecting the relative price. The GSF on the other hand works via the interest rate channel, thus reducing unit costs of the green capital good. This transmission channel via the interest rate, however, is weaker limiting the overall share of green capital that can be maximally achieved with the GSF to about 120 compared to the BAU (Fig. D.2a). Banking sector's climate sentiments play out for the relative capital goods prices as before. Climate sentiments let the bank anticipate a lower profitability of the brown sector which then already grants more and cheaper loans to the green capital good sector before the introduction of the carbon tax. This allows the green capital good sector to be relatively more competitive and thus have lower relative prices in case of the banking sector having climate sentiments. A combination of a carbon tax and the GSF ($CTax + GSF$) has stronger effects combining price reductions for green (via credit conditions of GSF) and price increases for brown capital goods (via the carbon tax). Redistribution and the carbon tax has a slightly stronger effect because of higher demand (Fig. D.1a), inducing more green investments and thus stronger relative productivity changes (Fig. D.2b).

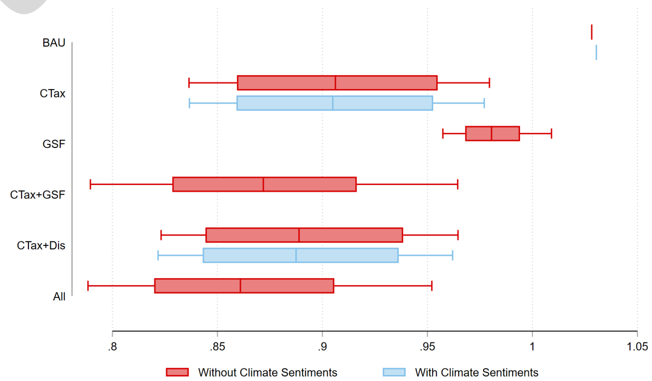
Figure D.1: Sensitivity of Macroeconomic Indicators y



(a) Real GDP (y)



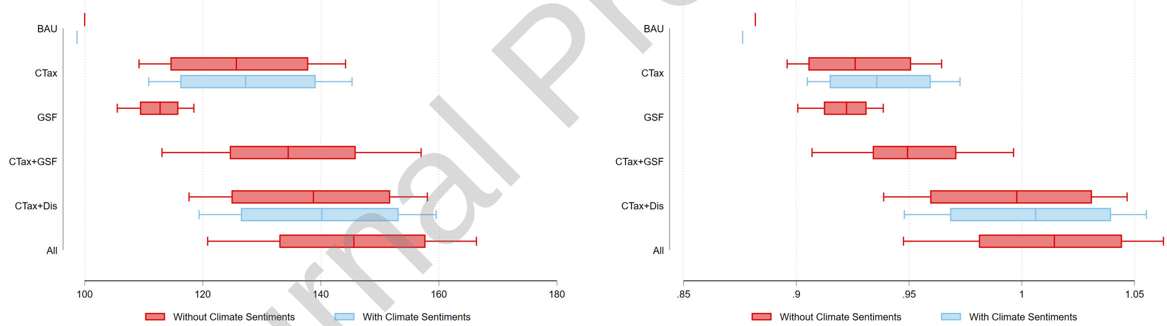
(b) Consumption Good Prices (p^N)



(c) Green/Brown Capital Goods Prices (p^G/p^B)

In the main paper the share of green capital is calibrated for all climate-aligned policy scenarios to be 45% at the end of the simulation run. Here we test the sensitivity of the green capital good share with respect to different levels of distinct climate-aligned policies (Fig. D.2a). We observe that the CT is more effective in stimulating a high share of green capital while the GSF is limited to a maximum share of about 120 compared to the BAU with zero risk weight for green loans. This indicates that the transmission channel of the GSF through the change in the credit conditions (thus reducing green capital goods prices while not directly affecting brown capital goods prices) is overall limited. The GSF seems to be effective and having low detrimental effects for the real economy in low ranges of emission reduction targets (via a higher green capital share). In contrast, achieving larger emission reductions would require fiscal policies, namely a carbon tax. At the same time, the GSF could raise concerns of a green bubble in financial markets because it requires a strong improvement of credit conditions for the green capital good sector, thus potentially fostering projects that could be unprofitable. Climate sentiments play out in a slightly higher share of green capital, due to lower relative prices of green and brown (Fig. D.1c) and better relative productivity performance of the green capital good sector (Fig. D.2b). Meanwhile, combinations of different climate-aligned policies and redistribution of the carbon tax revenues result in a higher green capital share since the effect size is higher.

Figure D.2: Capital Goods Indicators



(a) Share of green capital (ϕ^G) (b) Green vs. Brown Productivity (ϵ^G/ϵ^B)

We observe that the carbon tax fosters stronger green capital productivity improvements compared to brown productivity (Fig. D.2b) than the green supporting factor. However, the difference in green capital share (Fig. D.2a) between a carbon tax and a GSF scenario is larger than the difference in relative productivity of green and brown for these two policy scenarios. This indicates that the GSF is relatively better in stimulating green investments and thus green productivity improvements. At the same time the share of green capital goods not only relies on relative productivity improvements (also resulting in relative lower prices of green capital goods) but also on relative prices, which are stronger affected by the carbon tax by making brown capital goods directly more expensive. As before, policy combination and redistribution have stronger effects on relative productivity as a result of stronger policies but also a higher demand effect which fosters investment in green capital goods thus stimulating productivity improvements.

When taking a look at banking sector's indicators we see that the carbon tax strongly increases the non-performing loans ratio in the consumption good sector (Fig. D.3a), while climate sentiments lower the rate slightly due to a lower carbon tax burden following the earlier and higher share of green capital goods in the climate sentiments' scenario. The GSF, on the other hand, has only small effects: GDP effects are less detrimental (Fig. D.1a) and the consumption good sector is only affected by price decreases for the green capital good sector. This, in turn, is not sufficient to affect its profitability and hence the $NPLs$ ratio of the consumption good sector. Redistribution of the CT revenues to households stimulates aggregate demand and GDP and thus it only slightly affects F's $NPLs$.

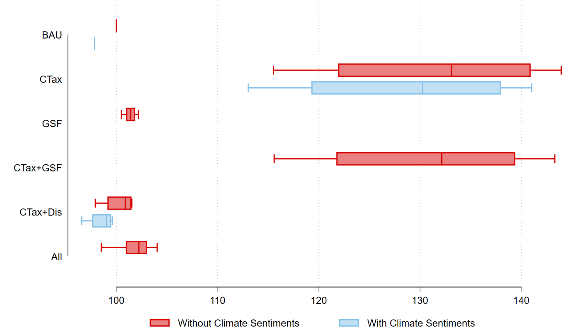
The $NPLs$ ratio of the brown capital good sector (Fig. D.3b) shows a steep increase with the introduction of the carbon tax by reducing brown profitability. Climate sentiments play out as a result of different credit conditions, due to the expectation of lower profits for the brown capital good sector, and thus lower loan exposures of the brown capital good sector (Fig. D.3e). The GSF has less effects on the $NPLs$ ratio of the brown capital good sector. Indeed, it does not directly penalize the brown capital good sector but it works indirectly via interest rate and relative productivity channels. As for the variables before, a combination of climate-aligned policies and redistribution of CT revenues have stronger effects. However, $NPLs$ ratio for the brown capital good sector only slightly increases in comparison to the simple CT scenario, because the higher demand has a positive feedback on brown profitability and hence on $NPLs$.

$NPLs$ ratio for the green capital good sector (Fig. D.3c) is rather low in all climate-aligned policy scenarios. This result is not surprising because all the climate policy scenarios foster a higher green capital goods share. We notice that low levels of a CT and GSF have similar effects on the $NPLs$ ratio. They work via different channels: the GSF makes green capital goods cheaper and more productive, while the CT makes brown capital goods more expensive in our model. Climate sentiments play out in a slightly lower reduction of the $NPLs$ ratio. A combination of different climate-aligned policies and redistribution of carbon tax revenues to households lowers the $NPLs$ ratio of the green capital good sector even more due to demand effect sizes and productivity effects.

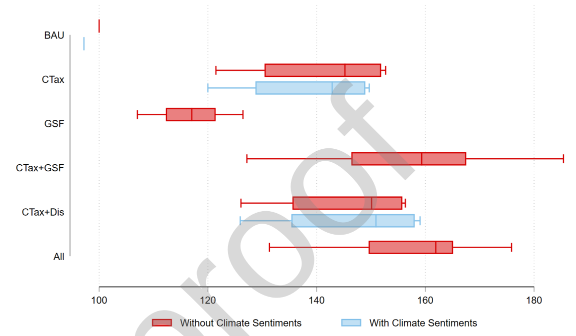
When assessing the loan exposure of the firm sector (Fig. D.3d) we notice that loan exposure decreases with the CT. This effect is driven by the detrimental effects on GDP (Fig. D.1a) and by the green capital productivity improvements that require less green capital stock per unit of output, due to its higher efficiency. We see that climate sentiments play out by having a higher loan exposure of the firm sector due to less detrimental GDP effects, thus stimulating investments, which drive the higher productivity improvements for green capital goods requiring less investment for serving demand. In the GSF, the loan exposure of the firm sector is only slightly lowered due limited impacts on GDP. Nevertheless, the induced productivity improvements for green capital also require less green capital stock investment of the consumption good firm and hence less credit financing. The productivity improvements further increase with the combination of GSF and CT (Fig. D.2b) thus lowering consumption good firm's loan exposure even further. In the scenarios characterised by the carbon tax redistribution, the demand effect and relative productivity effect work into different directions. Higher demand induces higher borrowing of the consumption good firm to finance its investment needs, while stronger productivity increases require less capital input per unit of output thus requiring less investment needs and borrowing. This results in a slightly lower exposure of the consumption good firm in the $CTax + Dis$ and All scenarios.

Loan exposure of the brown capital good sector (Fig. D.3e) shows similar dynamics as for the consumption good sector exposure with the difference that stronger GDP results in even lower loan exposure for the brown capital good sector in the scenarios with the carbon tax redistribution.

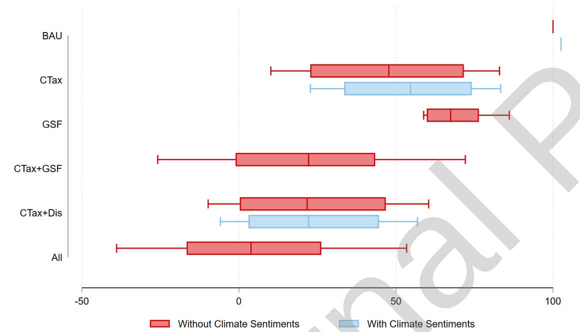
Figure D.3: Bank Indicators



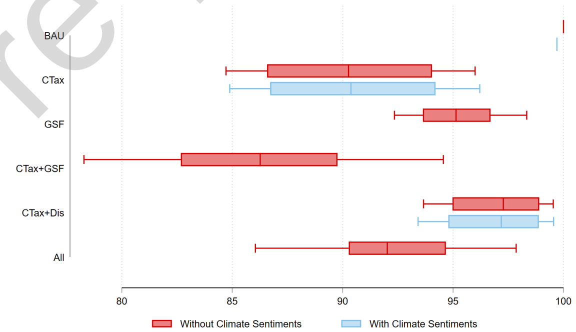
(a) Nonperforming Loans ratio (ξ^F) F



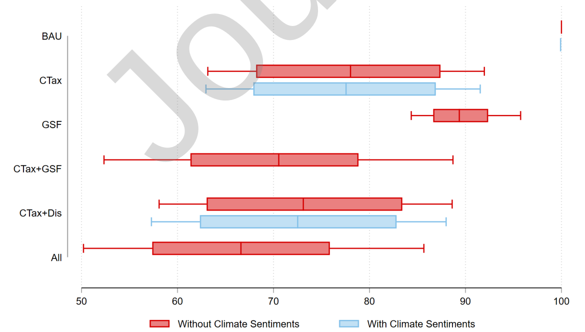
(b) Nonperforming Loans ratio (ξ^B) B



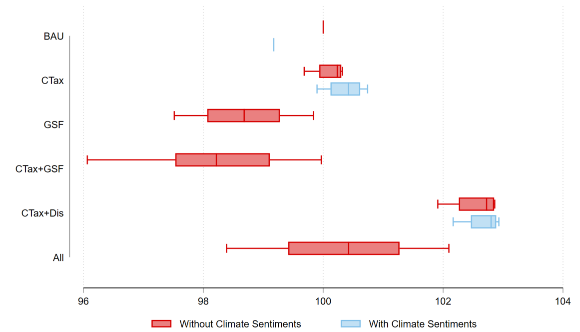
(c) Nonperforming Loans ratio (ξ^G) G



(d) Loan Exposure (L^F) F



(e) Loan Exposure (L^B) B



(f) Loan Exposure (L^G) G

This is due to the fact that the brown sector's economic competitiveness is penalized compared to the green capital good sector thus lowering its investment needs and loan exposure. Climate sentiments have stronger effects on relative productivity and relative prices of green versus brown, lowering the share of brown capital requiring less credit-financed investment.

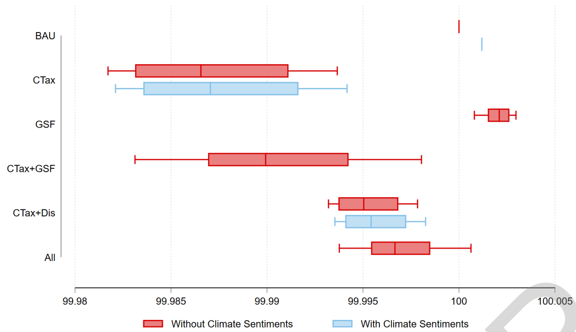
Loan exposure of the green capital good sector only slightly increases for scenarios without carbon tax redistribution (Fig. D.3f). This result emerges as a consequence of strong green productivity improvements and detrimental demand effects (Fig. D.1a) that impact on the investments of the green capital good sector. Decreasing green capital investment balances out with the relative higher demand for green capital goods, which requires higher green capital investment needs. In case of climate sentiments, we see that the better GDP performance (Fig.D.1a) outweighs the additional relative productivity gains (Fig. D.2b), thus leading to a higher loan exposure for G. In scenarios with the redistribution of the carbon tax revenues to households, overall GDP slightly increases. Thus, the higher demand for green capital goods overtakes the productivity improvements, resulting in higher investment needs and thus loan exposure.

As in the main paper, the CAR does not show large deviations from its desired level since the banking sector reacts to deviations from its target value by adjusting its lending behavior or interest rates (Eq. 30). Nevertheless, we notice small variations for CAR values depending on the type of the climate-aligned policy and banking sector's climate sentiments (Fig. D.4a). In particular, the CT seems to have slight negative effects due to the worsening economic conditions that lead to higher $NPLs$ ratios for the banking sector (Fig. D.3a-c). Further, the strong relative price effect that increases the share of green capital goods D.2a) contributes to reduce profits in the brown sector and thus a higher $NPLs$ ratio. This also affects the CAR negatively. Climate sentiments play out positively due to the positive GDP effects (Fig. D.1a) and lower $NPLs$ ratios, compared to the case without climate sentiments. The GSF in turn, has positive effects on the CAR due to avoided negative effects on GDP; milder relative effects of green versus brown D.2a); lower risk weights for green loans (which is the purpose of the GSF in the first place).

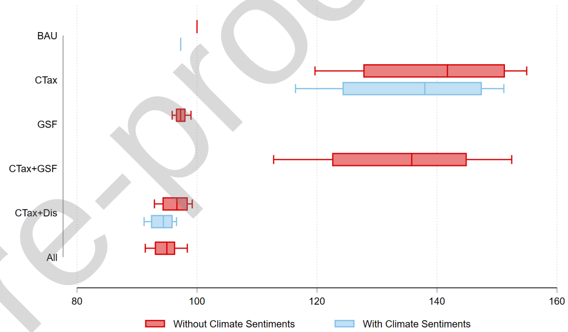
Finally, we test the sensitivity of the interest rate to different levels and combinations of the climate-aligned policies in our model. For the consumption good sector (Fig. D.4b) we see a strong increase in interest rates in carbon tax scenarios that are not redistributed to households ($CTax\&CTax + GSF$) since profits of the consumption good sector go down as a result of lower demand and GDP. Banking sector's climate sentiments slightly reduce the interest rate increase of the carbon tax, due to a higher profitability of the consumption good sector as a result of green capital productivity gains lowering investment needs and a better output situation compared to the case without climate sentiments. The GSF alone, as well as the redistribution of carbon tax revenues to households have only slight negative effects for GDP (Fig. D.1a), resulting in less affected profits and thus interest rate adjustments for the consumption good sector at different degrees of the climate-aligned policy.

As we can see in Figure D.4c, all climate-aligned policy scenarios result in improved terms of interest for the green relative to the brown capital good sector. The GSF, working via a direct interest rate reduction for the green capital good sector, has the strongest impact in that regard. The carbon tax impact is smaller since it works indirectly via reduced profits of the brown capital good sector and increased profits of the green capital good sector. Climate sentiments play out only slightly, since the graphs do not allow to show the timing of the interest rate setting which occurs in case of climate sentiments before the carbon tax is implemented. Since we look at end

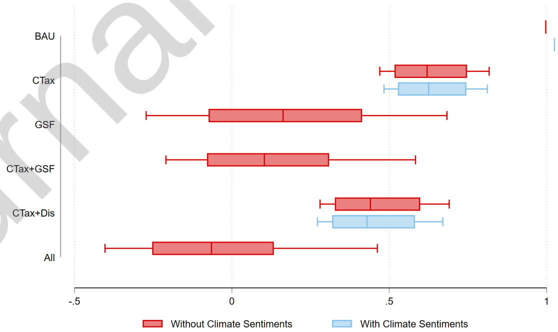
Figure D.4: Interest Rates & CAR



(a) Capital Adequacy Ratio (CAR)



(b) Interest Rate (r^F) F



(c) Relative Interest Rate (r^G/r^B)

of scenario run values after the carbon tax implementation, the relative interest rate changes are very similar for the banking sector having or not having expressed climate sentiments. However, the timing matters for overall outcomes, as we can see in the sensitivity analysis above. We see that redistribution of carbon tax revenues to households reduces relative interest rates of green to brown stronger due to higher green capital investments leading to higher green capital productivity gains, accelerated by the higher demand.

Appendix D.2. Correlation of climate-aligned policies with core model variables

Second, we demonstrate the impact of the paper parameter value of the climate-aligned policy on core model variables by showing their correlation of an increase of that policy parameter to the core model variable. This gives us a hint on the *direction* of the changes, that is whether the core model variable increases or decreases with a higher policy parameter. As we can see from Figure D.5a, a higher carbon tax, further decreases GDP with a high correlation, indicated by the medium degree of red. We conduct the analysis with the end of the simulation outcomes. As above, we distinguish between a scenario with banking sector's climate sentiments and a scenario without climate sentiments. Positive correlation is expressed in different shades of green, while negative correlation is shown in different shades of red. This allows us to get a clear picture on the transmission channels and final impacts of the carbon policy for real and financial model variables.

Appendix D.2.1. ***Without*** *Climate Sentiments*

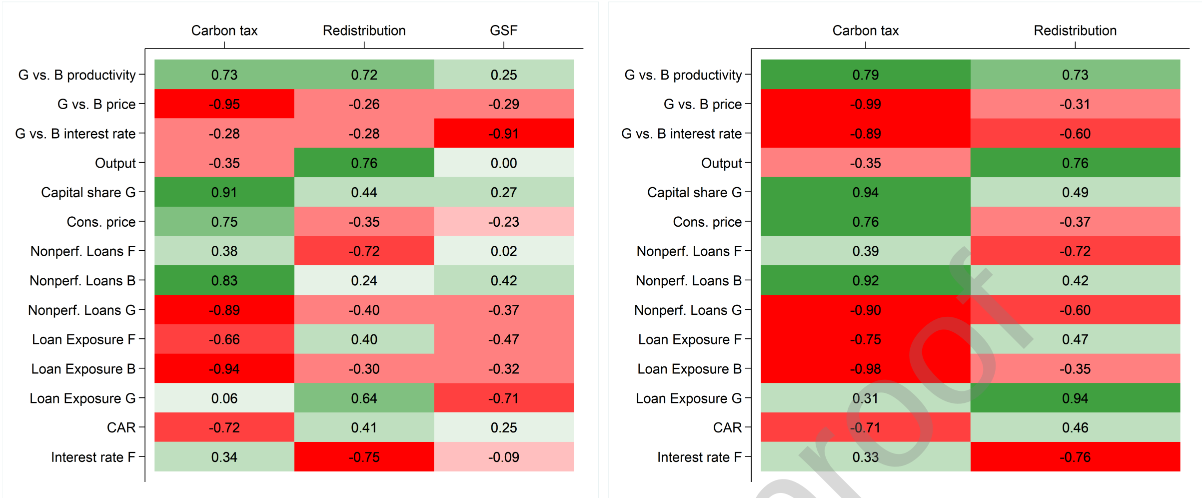
We first analyze the correlation of an increase in the climate-aligned policy parameters to the core model variables with **no** climate sentiments (Fig. D.5a). An increase in the carbon tax is strongly correlated with an increase in green capital productivity relative to brown capital productivity, indicated by the strong shade of green, no matter whether what happens to carbon tax revenues. For a non-redistributed carbon tax the strong relative price effect is the reason for this, causing a shift from brown to green capital goods. In case of redistributing carbon tax revenues back to households, it is partially relative prices that are affected but to a lower extent (G vs. B price) and a main part is of increased output. This induces higher additional investments which are now to a higher share green. In case of an increasing GSF we observe weaker correlation to improvements of relative green versus brown productivity, since the main transmission channel is the relative interest rate (G vs. B interest rate) representing a more indirect and weaker impact of the credit channel compared to the direct cost channel of a carbon tax. Output seems uncorrelated to changes in the degree of the GSF, since it mainly induces a reallocation without affecting households' budget constraint. For both carbon tax scenarios, relative interest rates do not respond as much as in the GSF case, indicating the main transmission channel working via relative prices and accompanying productivity changes in the real economy. Taking a look into the green capital share, we see that an increase in the carbon tax that is non-redistributed shows the highest correlation (dark green), whereas it is weaker for the redistribution case and even more so with the GSF. This supports again the paper results that directly making brown goods more expensive is a stronger signal to the market than making green capital goods cheaper and more competitive via lower capital costs. In case of the redistribution this effect is weaker since it is partially offset by positive output correlation and a negative correlation to consumption good prices, relaxing the budget constraint for households. In contrast, without redistribution, the consumption good price increases with an increasing carbon tax rate.

Taking a look into the financial sector, we observe non-performing loans for the consumption good sector being positively correlated to an increase in the non-redistributed carbon tax and almost no correlation to an increasing GSF. This result seems to be mostly driven by the output changes, which are positive for the redistribution case, thus lowering the non-performing loans ratio for F with an increasing redistributed carbon tax. The overall better economic conditions in that case are also the reason why the non-performing loans ratio for B is less strongly correlated to an increase in the redistributed carbon tax compared to the non-redistributed case and even the GSF. That it is still positively correlated, despite the positive GDP effect, gives us an indication that the reallocation of capital goods induced by relative prices and relative productivity dominates the overall GDP effect in that scenario. Finally, we see for the green capital good sector, that non-performing loan ratios for G are falling in all scenarios, with increasing policy strength, since each climate-aligned policy favors directly or indirectly the green capital good sector. The effect is mostly pronounced in case of the non-redistributed carbon tax since it induces a strong readjustment of the capital goods portfolio due to the relative price effects thus leading to overall higher profits for the green capital good sector even though the overall macroeconomic conditions are worsened. The overall better economic conditions in the *Redistribution* and GSF scenario also explains, why non-performing loans ratios are less strongly directly correlated to the increase in those policies, since they favor other sectors too. The relevance of the GDP effect becomes even clearer when taking the loan exposure for the non-redistributed carbon tax into account. It decreases for F and B as a result of overall less demand, productivity gainings for the green capital good and readjustment of the capital goods demand in favor of green. For G, loan exposure only increases slightly, despite the readjustment of capital goods demand, due to the overall GDP effect and productivity gains requiring also less investment of the green capital good sector. In case of the redistribution, we observe a positive correlation with loan exposure for F and G since increasing demand dominates productivity gainings. For B, the relative price and productivity effect lowers demand for brown capital goods requiring less investment and thus less external financing. For the GSF with its neutral effects on GDP, an increase in the policy strength reduces loan exposure of all sectors for F and G due to productivity gaining outweighing the higher demand for green and for B because of the indirectly induced demand for brown capital goods. Capital adequacy ratio is negatively correlated with an increase in the non-redistributed carbon tax due to the detrimental effects on the real economy affecting NPLs and profits of the banking sector. The opposite is the case for the redistributed carbon tax, for the same reasons. A stronger GSF is correlated with an increasing CAR because of the avoided detrimental GDP effects and since the model does not account for asset price volatility yet. Finally, interest rates of F are positively correlated with an increasing non-redistributed carbon tax, indicating that an increase in the carbon tax increases interest rates for F due to lower profits and demand. The demand effect is the dominating effect in the *Redistribution* case, increasing revenues and profits for consumption good firm thus allowing lower interest rates. Finally, an increasing GSF is slightly negatively correlated with the interest rate for F, since productivity gains for green capital goods and lower prices due to lower interest rates are transmitted to the consumption good sector allowing slightly higher profits and thus lower interest rates.

Appendix D.2.2. ***With*** *Climate Sentiments*

Next, we are interested in assessing how the correlation of increasing non-redistributed or redistributed carbon tax revenues to the model's core variables might change with distinct banking

Figure D.5: Heat plot of climate-aligned policy impacts



(a) Climate sentiments: **Without** (b) Climate sentiments: **With**

sector's climate sentiments. The first heatplot (Fig. D.5b) portrays the correlations, when banking sector's expectations about future profits when the carbon tax is implemented match the realized outcome afterwards. In short, its expectations and following measures were *adequate*. In general what we see are stronger pronounced effects of the correlations described above. Since the transmission channel of climate sentiments on banking sector's profit expectations is via the interest rate channel, non-surprisingly the relative interest rate (*G vs. B interest rate*) shows a stronger correlation with a tax level increase than it did in the *no* sentiments case. Another interesting observation is that while financial variables such as loan exposures and non-performing loan ratios show more pronounced effects due to the stronger correlations of relative productivities, relative prices and relative interest rates resulting in stronger correlations with green capital share, output does not show differences to the case of no climate sentiments. This indicates that the main benefits we might be able to expect of stronger banking sector's climate sentiments might play out via relative benefits of green versus brown and in the credit sector, rather than for real economic outcomes.

Appendix E. Core Parameter Alterations

Interest rate adjustments affecting the credit sector and capital productivity changes influencing the real economy are important transmission channels of climate-aligned policies. To assess the relevance of the applied parameter values in the main paper for climate-aligned policies to work out, we conduct several parameter alterations for the interest rate channel as well as the productivity channel. In particular, we analyze how the three climate-aligned policy scenarios, GSF ($SC1$), carbon tax with no sentiments ($SC2$) and carbon tax with stronger sentiments ($SC3$) affect core model variables, when the interest rate sensitivity to expected profits (κ_1) (Eq. 32) and either green (γ_ϵ^G) or brown (γ_ϵ^B) capital productivity sensitivity with respect to new investments (Eq. 7) are altered.

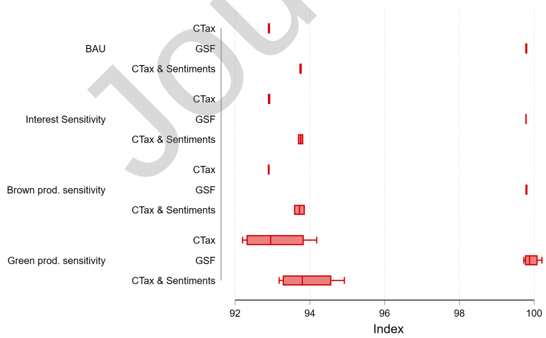
All graphs are indexed to a baseline scenario with **no** climate-aligned policy and **no** parameter alterations, representing 100. Further, we conduct a BAU simulation, which in this case is the end-of simulation variable outcome for the climate-aligned policy scenarios (GSF, $CTax$, $CTax\&Sentiments$) with the parameter values we apply in the main paper. We then alter either interest rate sensitivity, brown productivity sensitivity or green productivity sensitivity to assess the relevance of these parameter values for climate-aligned policy results.

Table E.8: Core parameter range

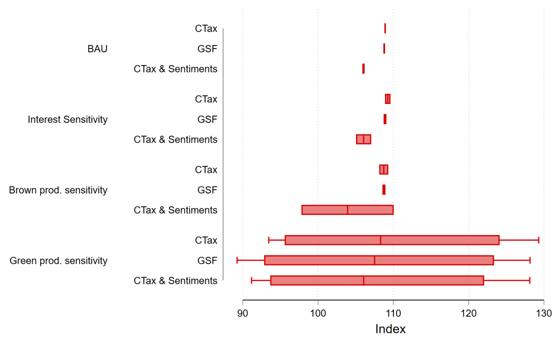
Core parameter	**Parameter range**	**Step size**	**Value applied in paper**
Interest rate sensitivity (κ_1)	5% – 15%	5%	10%
Brown productivity sensitivity (γ_ϵ^B)	0% – 10%	5%	5%
Green productivity sensitivity (γ_ϵ^G)	0% – 20%	5%	10%

First, we assess the impact of climate-aligned policies on GDP when interest and capital productivity sensitivities are altered (Fig. E.1a). As in our main paper results, the BAU case with no altered parameter values leads to detrimental GDP effects for the carbon tax ($CTax$) and slightly less the carbon tax ($CTax\&Sentiments$) scenarios, whereas the GSF climate-aligned policy scenario is fairly neutral to GDP. When taking a look into altered interest rate sensitivity, we observe almost no impact with either higher or lower parameter values for interest rate sensitivity. Hence, we see that policy outcomes for GDP are not very sensitive to interest rate sensitivity changes. The same can be said about brown productivity changes, which also show barely any impact on GDP. Finally, when looking into altered green productivity sensitivity, we observe minor changes in GDP, especially for both carbon tax scenarios, being less detrimental with higher green productivity sensitivity with respect to new investments.

Figure E.1: Sensitivity of Core Parameter I



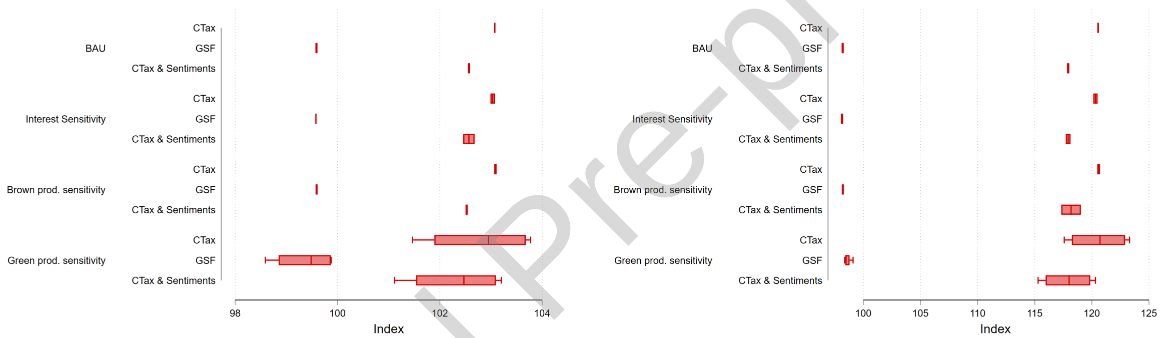
(a) Real GDP (y)



(b) Green capital good share (ϕ^G)

Second, we analyze the impact of altered interest and capital productivity sensitivities for the share of green capital (Fig. E.1b). For the BAU, we see again the same impact as in the paper version, which are designed for achieving 45% green capital share at the end of the simulation run. For altered interest rate sensitivity, we see almost no difference for $CTax$ and GSF, whereas we observe a slight impact in the case of $CTax\&Sentiments$, which can be explained by the important role the interest rate channel plays for stronger climate sentiments to play out. Assessing different sensitivity levels of brown capital productivity, we again see barely any difference in case of $CTax$ and GSF, whereas there is quite some range of green capital share outcomes for altered brown capital productivity sensitivity in case of $CTax\&Sentiments$. This gives us an insight on the importance of capital productivity responsiveness for stronger climate sentiments to play out. Stronger brown capital sensitivity reduces the share of green capital because it makes investment in green capital sector less attractive, which investors with stronger climate sentiments take into consideration. Finally, green productivity sensitivity seems to be quite important for model outcomes, indicated by the wide range of outcomes in all three climate-aligned policy scenarios. This demonstrates the importance to estimate and form assumptions for green technical change in response to climate-aligned policies since this could be crucial regarding their success or failure.

Figure E.2: Sensitivity of Core Parameter II



(a) Consumption prices (p^N)

(b) Interest rate F (r^N)

Next, we take a look at the responsiveness of consumption good prices to altered interest and capital productivity sensitivities in the different climate-aligned policy scenarios (Fig. E.2a). As in the paper version, the BAU shows slightly lower consumption good prices in case of the GSF and slightly higher consumption good prices for $CTax$ and $CTax\&Sentiments$. In case of altered interest rate sensitivity and brown productivity sensitivity we observe no changes in all three climate-aligned policy scenarios. When green productivity sensitivity is altered, we observe a slightly wider range of outcome for all three different climate-aligned policy scenarios, indicating the role that faster and stronger green productivity evolvement could have in making consumption good prices lower because the green capital good is more competitive and thus cheaper. This again points to the importance of green capital productivity to become more competitive for avoiding detrimental effects with climate-aligned policies implementation.

Finally, we assess the responsiveness of the consumption good firm's credit conditions (its interest rate) with respect to the altered interest and capital productivity sensitivities in the different climate-aligned policy scenarios (Fig. E.2b). As before, we barely see any impact in case of altered interest rate and brown productivity sensitivity in all three climate-aligned policy scenarios compared to the BAU. For altered green productivity sensitivity, however, both carbon tax scenarios ($SC2\&SC3$) lead to different interest rate outcomes for the consumption good firm, whereas the GSF scenario barely shows any difference compared to the BAU. This demonstrates again the different transmission channels that are in play. The carbon tax directly affects the real economy by making brown capital goods more expensive thus reducing profits of the consumption good sector, which translate into higher interest rates to be charged. If substitution to green capital goods is cheaper due to higher productivity evolvement, the negative effect on profits is reduced and lower interest rates can be charged. The GSF on the other hand works via making green capital good production cheaper by improving its credit conditions thus not affecting profits of the consumption good sector much, thereby showing only limited effects on consumption good sector's interest rate.

Appendix F. Credit rationing

The paper results were based on a model specification of sector-specific interest rate setting of the banking sector based on its own capital adequacy ratio and on the credit score of the particular sector (Eq. 32). Thus, the banking sector reacts to (expected) changes of profitability of a sector with updating its credit conditions, that is making debt-financed investment more or less expensive. In this section we demonstrate a different mechanism by letting the banking sector not update credit conditions but the quantity it is willing to lend to a particular sector. Hence, the banking sector is adopting a credit rationing mechanism.

The credit rationing mechanism is defined consistently with recent SFC modelling (see Dafermos and Nikolaidi (2019a) but differences apply. First, as the difference to the credit channel mechanism in the main paper, the sector-specific interest rate is now exogenous (Eq. F.1) to demonstrate the effect of credit rationing instead of interest rate adjustments. However, the banking sector continues to adjust overall interest rates (e.g. for all sectors equally) to maintain its profitability and a stable capital adequacy ratio (Eq. 30).Second, the GSF works, as in the main paper above, by altering the green capital sector's interest rate, on top of the sector-specific credit rationing (see Section 4.3.1). As above, this affects the relative prices of green and brown capital goods, and thus indirectly has an effect on the brown capital good sector.[13]

Except for the following changes the model is the same as presented in the main paper. Now,the sector-specific interest rate is exogenous (Eq. F.1) but for the overall adjustments the banking sector conducts to maintain its profitability and a stable capital adequacy ratio (Eq. 30).

$$r_t^n = \bar{r} + r_t^v \tag{F.1}$$

Following Dafermos and Nikolaidi (2019a), we introduce a sector-specific debt service ratio DSR_t^n, which is the ratio of debt interest and loan repayments to expected profits $\tilde{\Pi}_t^n$ before interest

[13] We keep the GSF working through the interest rate channel, for the following reason. As pointed out in Section 4.3.1, the GSF working via interest rate effects, affects relative prices between green and brown capital goods and thus indirectly affects the brown capital good sector. The relative price effect results in altered relative demand for each capital good. We keep this mechanism the same here as in the main paper. If theoretically, the GSF would work via credit rationing, green capital good firms would get more access to credit. If, however, no strong green productivity effects would be induced, green capital goods demand would not automatically increase. The reason being, green capital goods not being more cost competitive. At the same time, loans granted to the brown capital good sector would not decrease (due to the absent relative price effect), since the GSF increases the leeway for banks granting green loans but does not restrict brown lending. Thus the GSF, working with a full credit rationing mechanism, could be less effective compared to the GSF with the interest rate channel. In fact, a brown penalizing factor, directly decreasing lending to the brown capital good sector, would instead be required.

payments (Eq. F.2). In contrast to the above presented model, banking sector's climate sentiments affect profit expectations that determine the expected debt service ratio of that sector and ultimately lead to stricter or less strict credit rationing dependent on sector's expected profitability.

$$DSR_t^n = \frac{r_t^n(L_{t-1}^n - NPL_t^n) + \rho L_{t-1}^n}{\tilde{\Pi}_t^n + r_t^n(L_{t-1}^n - NPL_t^n)} \quad (F.2)$$

$$CR_t^n = \frac{CR^{max}}{1 + r_0^{r_1 - r_2 DSR_t^n}} \quad (F.3)$$

$$LD_t^n = I_t^{T,n} - \eta D_t^n \quad (F.4)$$

$$LS_t^n = (1 - CR_t^n)LD_t^n \quad (F.5)$$

$$I_t^n = \eta D_t^n + LS_t^n \quad (F.6)$$

Credit rationing CR_t^n then follows from a maximum that the banking sector sets and the sector-specific debt service ratio (Eq. F.3) based on firms' expected profits effectively limiting the amount of loans that is granted to firms. In particular, firms face a target investment (same as before Eq. 10), which they need to finance. Following the pecking-order theory of financing (Myers, 1984), firms first rely on internal funds ηD_t^n and turn for the reminder to external funding constituting banking sector's loan demand LD_t^n (Eq. F.4). The banking sector then decides based on its conducted sector-specific credit rationing analysis which share of loan demand it is going to grant (Eq. F.5). This results in realized firms investment I_t^n (Eq. F.6), which can be lower than target investment and thus constraining firms to fully satisfy demand. In fact the economy becomes now quantity constrained.

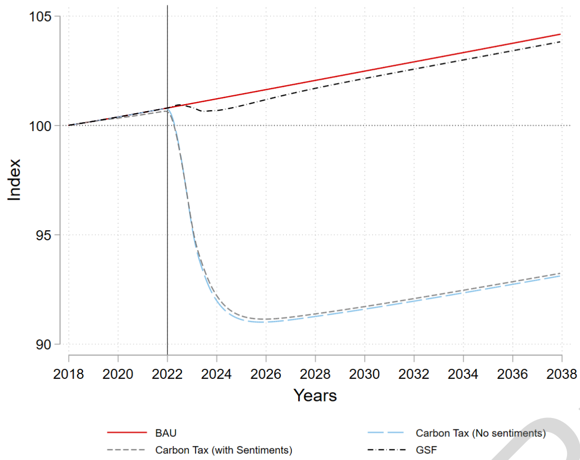
Subsequently, we show the model results with the above discussed model changes, whereas we aim for highlighting the differences compared to the simulation results presented in the main paper.

In case of macroeconomic indicators (Fig. F.1) we see no qualitative changes compared to the main paper model for GDP, consumption good prices and relative prices of green and brown capital goods. The differences of a carbon tax and the green supporting factor are slightly stronger pronounced and the role of banking sector's climate sentiments becomes smaller indicating that the effect channel for climate sentiments is weaker via credit rationing than adjusted interest rates.

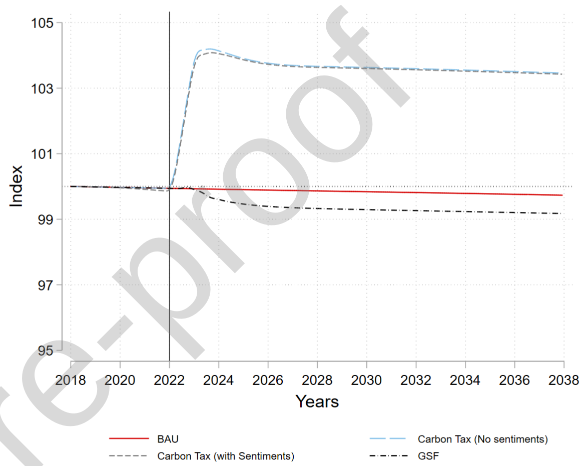
With respect to capital goods indicators (Fig. F.2) the key difference from the paper version is that in the carbon tax scenarios the relative capital good's sector productivity is at all times during the simulation lower compared to the green supporting factor scenario, thus emphasizing even stronger the transmission channel of the green supporting factor.

Taking a look at banking sector indicators (Fig. F.3), a difference with introducing credit constraints instead of adjusting credit conditions accrues. The introduction of a carbon tax results in stronger credit rationing for the consumption good firm and the brown capital good producer, while the green supporting factor even slightly lowers credit constraints for those sectors. This transmits into lower loan exposure in those sectors in all scenarios. However, the lower credit rationing in the GSF scenario also leads to a lower reduction in loan exposure, whereas in the main paper all scenarios face more similar loan exposure adjustments. The green capital good sector benefits in all scenarios from lower credit rationing, however the GSF scenario is also here more advantageous. This translates into a key difference between the credit rationing and the credit

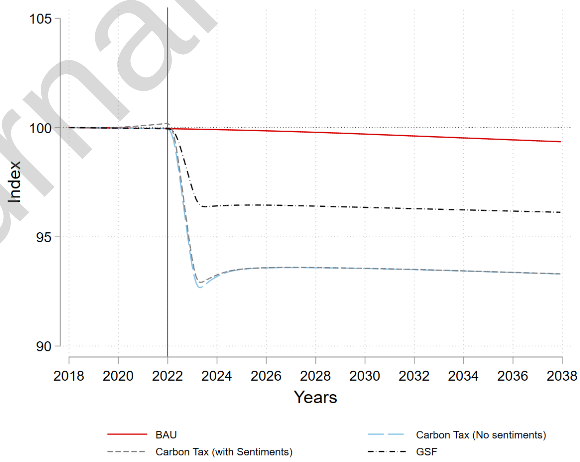
Figure F.1: Macroeconomic Indicators



(a) Real GDP (y)

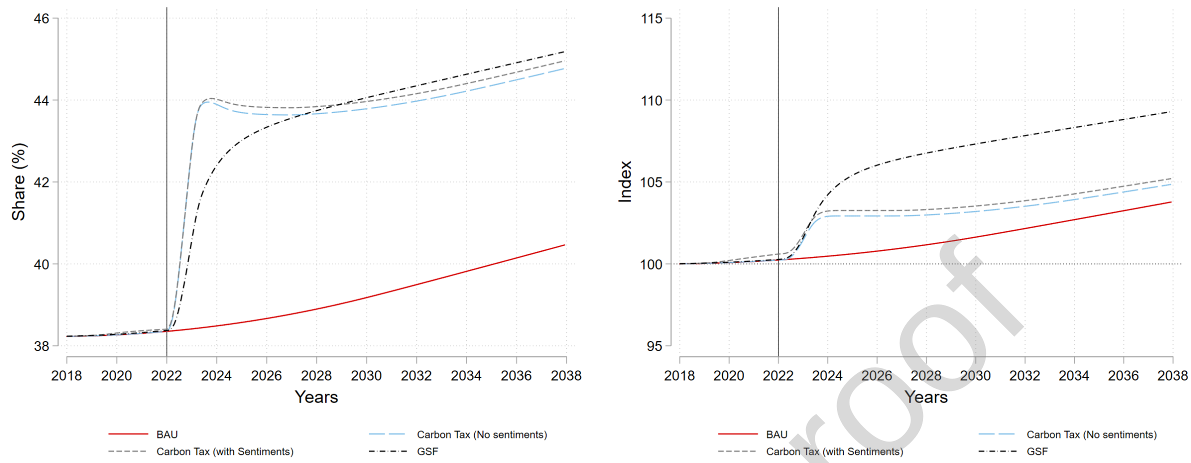


(b) Consumption Goods Prices (p^N)



(c) Green/Brown Capital Goods Prices (p^G/p^B)

Figure F.2: Capital Goods Indicators

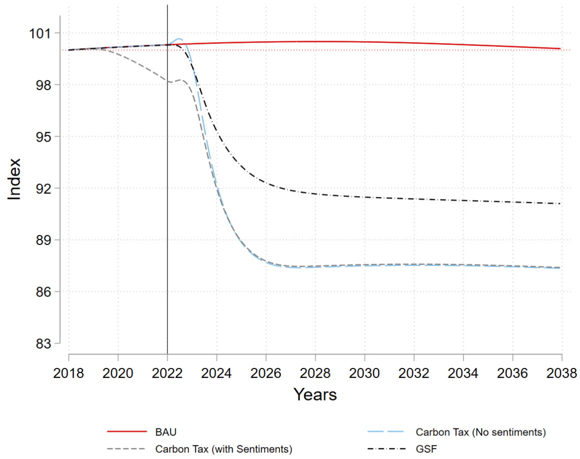


(a) Share of green capital (ϕ^G) (b) Green vs. Brown Productivity (ϵ^G/ϵ^B)

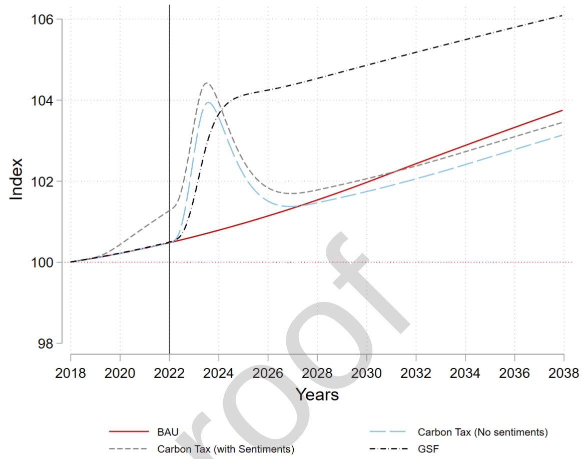
condition mechanism, since the GSF increases banking sector's loan exposure to the green capital good sector compared to the BAU and the carbon tax results only in a slight decrease of the green loan exposure.

Finally, we see that the capital adequacy ratio of the banking sector is stronger negatively affected in case of the GSF scenario with credit rationing compared to the case of credit conditions (Fig. F.4). Interest rates now only change with respect to the capital adequacy target of the banking sector in order to maintain profitable. As we can see the charged interest rates are higher in case of the carbon tax scenarios, similar to the case of altering credit conditions, but for the GSF the interest rates are lower. This can be explained by the lower credit rationing for those sectors in case of the GSF allowing the banking sector to grant more loans and hence generate higher profits. In case of the green capital good sector, we see that the GSF results in a strong interest rate reduction, which is required in order to achieve the target green capital share of 45%. This points out the potential problem of the GSF, which is similar to the main paper results but probably even stronger pronounced. The very low interest rate for the green capital good sector could raise concerns about a green bubble, while at the same time the maximum share of green capital goods that can be achieved via a GSF is limited (see sensitivity analysis). At the same time, the GSF with credit rationing has a lower indirect effect on brown capital good firms. As outlined above, the GSF with credit conditions works by directly lowering green capital costs. It also works indirectly, since the lower demand for brown capital goods results in lower profits. This leads the banking sector to charge higher interest rates for the brown capital good sector. In contrast, when the credit rationing is in place, the negative effects on brown firm's demand are smoothed due to the lack of change in brown interest rates. This contributes to limit adjustment in brown capital good sector's employed capital stock, and to lower the adjustment of banking sector's loan exposure to the brown sector. If at a later stage, the government would decide to implement accompanying climate policy measures (e.g. a carbon tax), the fact that the economy did not react strong enough to the signaling effect of the GSF by changing the relative distribution of green and brown, could

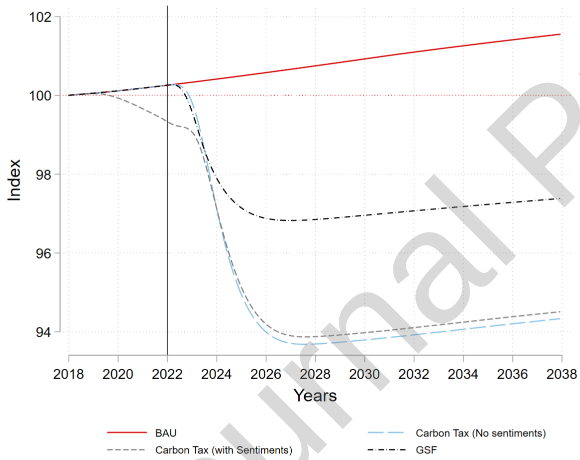
Figure F.3: Bank Indicators



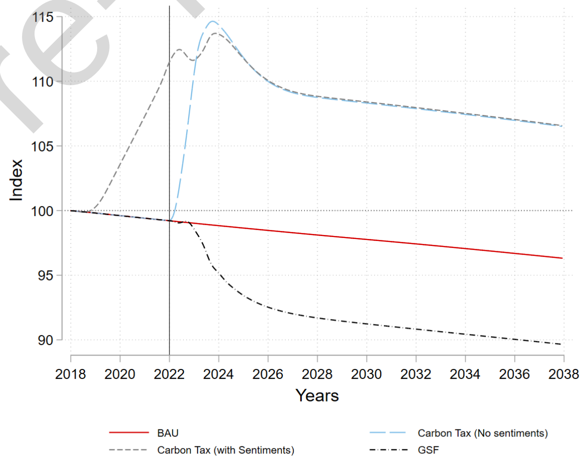
(a) Loan Exposure (L^B) B



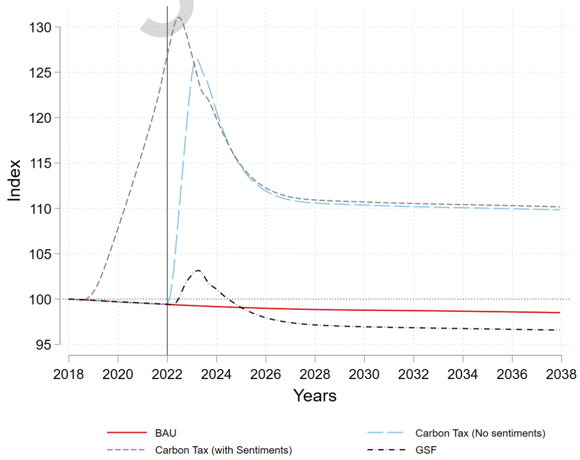
(b) Loan Exposure (L^G) G



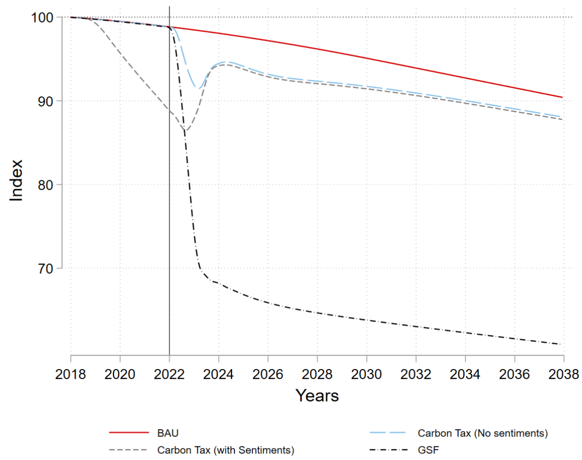
(c) Loan Exposure (L^F) F



(d) Credit rationing F



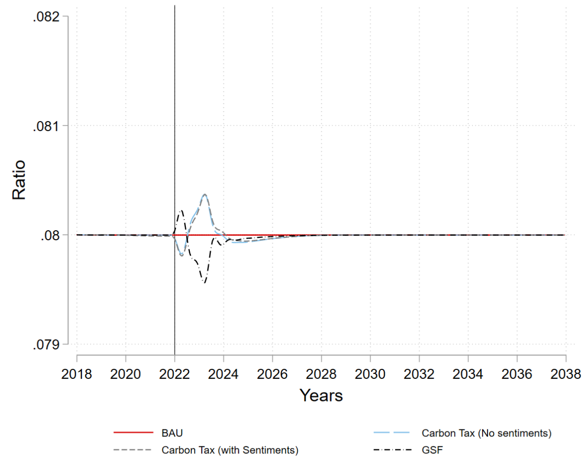
(e) Credit rationing B



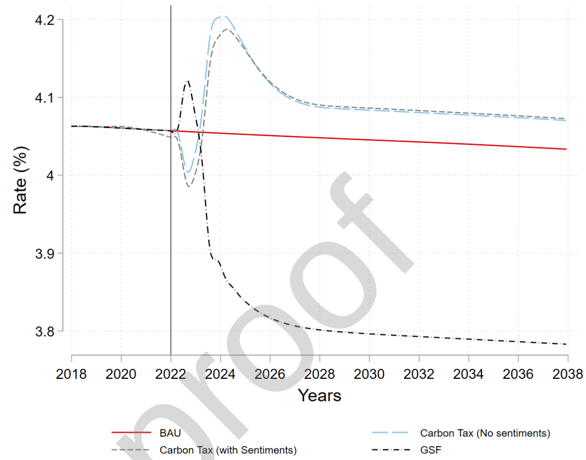
(f) Credit rationing G

increase the risk of carbon stranded assets.

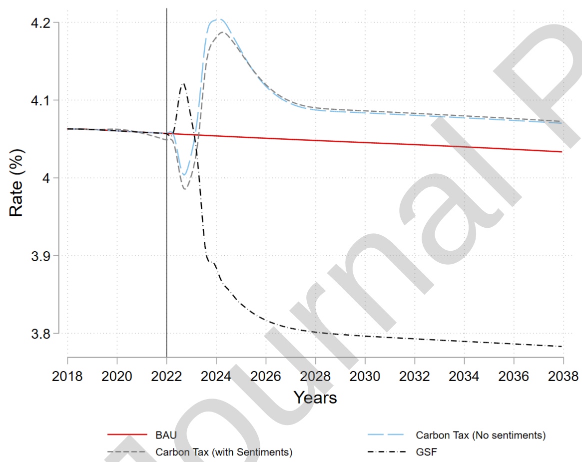
Figure F.4: Interest Rates & CAR



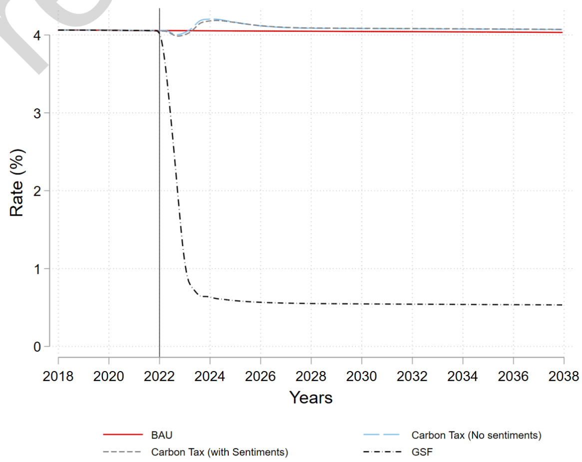
(a) Capital Adequacy Ratio (CAR)



(b) Interest Rate (r^F) F



(c) Interest Rate (r^B) B



(d) Interest Rate (r^G) G

Highlights of the paper "Climate Sentiments, Transition Risk, and Financial Stability in a Stock-Flow Consistent Model"
by Nepomuk Dunz, Asjad Naqvi and Irene Monasterolo

1) We develop a Stock-Flow Consistent macroeconomic model with forward-looking investment decisions

2) The model analyses climate finance policies' transmission channels on agents and sectors' balance sheets

3) We quantitatively assess the impact of a green supporting factor and a carbon tax on the economy and finance

4) Investors' climate sentiments can play a major role to avoid a disorderly low-carbon transition

5) Banks anticipating the climate policy impact are better off in preserving financial stability

6) A single climate policy is not enough to scale up low-carbon investments at the pace needed