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SOURCES AND POLICY RESPONSES

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ABSTRACT

Transition risk – the financial stability risk related with decarbonization – is a major source of concern. The literature has so far only studied transition risk caused by carbon tax shocks. This paper explores other potential sources of transition risk: two other policy sources – subsidies to abatement or to green producers – and two preference-based sources – a shock to consumer preferences and a shock to investor preferences. We develop an environmental dynamic stochastic general equilibrium model that includes a frictional financial sector, and we consider macroprudential policy responses to transition risks. These different shocks have different effects on the possibility of transition risk and lead to different macroprudential policy implications.

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1 Introduction

The threat from climate change is severe, and many policymakers and advocates argue for substantial and immediate action. Absent accompanying measures, another severe risk is that of transition risk – the potential impact that a transition to a cleaner economy could have on financial stability, especially if the transition is abrupt rather than gradual. These concerns are shared by many financial surveillance authorities and central banks.[1] Transition risk refers to the potential macroeconomic impacts caused by a sudden transition to a low-carbon economy when financial markets experience large losses in response to an unanticipated devaluation of carbon-intensive assets ("asset stranding"). Transition risk can emerge from various sources, including changes in public policy or preferences. These sources may not occur in isolation but may compound other financial and economic stability risks, like productivity shocks.

When economists have analyzed transition risk, they have focused on the risk caused by policy shocks from carbon taxation. Two such studies are Carattini et al. (2023) and Diluiso et al. (2021), which develop environmental dynamic stochastic general equilibrium (E-DSGE) models of climate policy with financial frictions. A carbon tax targets the climate externality, while financial frictions are addressed through macroprudential policy. Macroprudential policies can be used to avoid a financial crisis that could otherwise emerge from the abrupt implementation of a carbon tax. Carattini et al. (2023) show that even a moderate carbon tax shock in the order of $20-30 per ton of CO_2 above market expectations can lead to financial instability, though macroprudential policy can mitigate the transition risk. In a model with financial frictions, a well-known feature of real-world economies, a sudden shock can lead to a credit crunch akin to widespread asset fire sales, so that the initial effect of the climate policy shock can get substantially amplified. Diluiso et al. (2021) focus on a more gradual and fully an-

[1] See e.g. ESRB (2016); Bank of England (2018); Banque de France (2019); Bolton et al. (2020); ECB (2021); Rudebusch (2021). In a 2015 speech, the former governor of the Bank of England Mark Carney first warned of transition risk (Carney 2015). Nobel laureate Joseph Stiglitz declared transition risk a major threat potentially leading to a more severe version of the 2008 global financial crisis: https://www.scmp.com/news/china/article/3135977/us-economist-joseph-stiglitz-warns-carbon-pricing-mismatch-may-trigger (last accessed, September 16, 2024).

ticipated transition response to a climate policy shock, which does not require macroprudential policy since markets are not caught off guard.

Our paper studies potential transition risk from several sources, beyond just carbon tax shocks, and assesses whether such sources can also lead to a potential financial crisis and, if so, what the policy responses to these additional sources of risk may be. The rationale for considering additional sources of transition risk is as follows. First, policy instruments other than carbon taxes can contribute to tackle climate change, and these alternatives may be more likely to be implemented than carbon taxes depending on a jurisdiction's political economy context. Second, changes in consumers' and investors' preferences can also lead to transition risk. Even when the scope for ambitious climate policy may be limited, preference changes may lead to important shifts in asset valuations, leading to the realization of transition risk in ways similar to a climate policy shock, but with potentially different policy implications. Unlike transition risk arising from policy shocks, transition risk arising from preference shocks occurs outside of the direct control of governments, which may not be able to ensure that transitions are gradual. Preference changes can be sudden, for instance driven by new influential figures in environmentalism, the release of new scientific information or the expansion of climate education, or social tipping points. We do not consider such shocks as unwelcome. Rather, we assess how careful policymaking can prepare the ground for the societal changes, policy-driven or otherwise, that are necessary to deal with the threat of climate change.

In this paper, we develop and use an E-DSGE model that includes a negative externality from greenhouse gas emissions and a financial sector plagued with frictions via a principal-agent relationship between lenders and banks, modeled after Gertler and Kiyotaki (2010) and Gertler and Karadi (2011). We extend the earlier models in Carattini et al. (2023) and Diluiso et al. (2021) by considering sources of transition risk beyond just a carbon tax. The five sources of transition risk we study fall into two categories. First, we consider three policy-driven shocks, including not only a carbon tax, but also subsidies for green producers and subsidies for abatement. Second, we consider two preference shocks, one among consumers and one among investors. We consider macroprudential policy responses to each potential transition risk, modeled as taxes or subsidies on banks' assets. The purpose of this macroprudential policy is to preserve financial stability, not to achieve any climate-related goal, although financial stability is achieved when the macroprudential policy differentially targets brown and green assets. Our model, calibrated to U.S. data, captures all of these avenues and describes how policy can respond in each case. We model each of these five shocks occurring independently, and we also consider shocks occurring simultaneously, as well as occurring simultaneously with a negative total factor productivity shock that leads to a recession.

We find important differences across the different types of shocks. When it comes to the policy shocks, the carbon tax triggers transition risk, consistent with the prior literature. A mechanism behind this result is asset stranding in the brown sector, by which we mean an abrupt devaluation of brown assets owned by the banks. By contrast, the abatement subsidy and green producer subsidy shocks do not trigger transition risk. In fact, those two subsidy shocks have expansionary effects, leading to an expansion during the transition rather than a recession. This is because they each directly or indirectly subsidize production. Though both of these shocks avoid transition risk and reduce emissions over the transition, in the long run the green production subsidy actually increases emissions, since the effect of stimulating the economy overall dominates the substitution effect towards the green sector.

We also see important differences across the two types of preference shocks. Transition risk can be triggered by a preference shock in households' preference for green consumption goods, which leads to a drop in aggregate investment and output. The green preference shock captures sudden changes in households' consumption preference. It shifts the households' demand away from brown goods, leading to lower asset prices in carbon-intensive sectors. The magnitude of the transition risk caused by a consumer preference shock is much larger than that caused by a carbon tax, when the two shocks are calibrated to cause the same magnitude decrease in emissions. By contrast, a comparable preference shock among investors affecting their preference for green assets does not trigger transition risk. While this shock leads to brown assets becoming stranded, generating equity losses in the financial sector, the increase in demand for green assets is more than offsetting, leading to an overall increase in economic activity.

Under all of the shocks that could lead to transition risk, the introduction of macroprudential policies mitigates this risk by decreasing the financial intermediaries' exposure to the brown sector. Thus, our results do not imply that transition risk makes these climate policies too dangerous to employ, only that financial regulators need to be cognizant of the relationship between climate policies and the financial sector. Furthermore, regulators should be aware of the potential for transition risk to occur from shocks beyond their control (preference shocks) and of their ability to contain this risk through macroprudential regulation. As mentioned earlier, macroprudential policy is used within central banks' mandate to maintain financial stability. It is not used to steer the economy towards cleaner forms of production. It is simply the case that, since transition risk is a function of the exposure to the brown sector, addressing transition risk implies encouraging banks to lend more to the green sector and less to the brown sector. As shown in Carattini et al. (2023), macroprudential policy on its own is not very effective at climate mitigation.

Finally, we see interesting implications when multiple sources of shocks occur simultaneously. For example, when a carbon tax occurs simultaneously with a consumer preference shock, the magnitude of the asset stranding and the decrease in banks' assets is amplified. When each of our five shocks occurs simultaneously with a negative total factor productivity shock that leads to a recession, the two shocks amplify each other, deepening the recession. Macroprudential policy can modestly address these concerns, though it is not fully able to accommodate the effects of the negative productivity shock.

This paper contributes to several strands of literature. It advances a body of research thinking about transition risk in the presence of financial frictions (Diluiso et al. 2021; Carattini et al. 2023; Giovanardi and Kaldorf 2023; Carattini et al. 2024). Our paper also informs policy work related with the first generation of climate stress tests and offers insights on improving the credibility of such exercises (see Bank of England 2018; Vermeulen et al. 2018; Allen et al. 2020; Alogoskoufis et al. 2021; Bank of England 2022; ECB 2022; Allen et al. 2023). We show that so far neglected sources of transition risk are important in terms of potential financial instability. The same applies to the combination of various shocks, an issue known as compounding of risk (Acharya et al. 2023). Further, we also apply the idea of reverse climate stress testing (Basel Committee on Banking Supervision 2017) and provide a key dimension that we consider climate stress tests should systematically consider, i.e. how large a transition shock may be under various economic conditions without creating concerns about financial instability. Our paper also adds to the literature, which goes back to Fischer and Springborn (2011) and Heutel (2012), developing environmental DSGE models (see Annicchiarico et al. 2021 for a review). Our paper also builds upon and adds to a stream of research in climate finance assessing the potential exposure of financial institutions and investors to transition shocks (e.g. Beatty and Shimshack 2010; Carattini and Sen 2019; Bolton and Kacperczyk 2021; Ramelli et al. 2021; Seltzer et al. 2022; Ivanov et al. 2023; Bauer et al. 2023; Aswani et al. 2024). Finally, our paper relates to previous work thinking about preference shocks in a variety of contexts (e.g. Bénabou and Tirole 2006, 2010; Pástor et al. 2021; Oehmke and Opp 2024).

2 Model Summary

In this section we briefly summarize the core features of the model. We relegate a full detailed description of the model to Appendix A; the full set of equilibrium equations are presented in Appendix B.

We consider a closed-economy E-DSGE model with two sources of inefficiencies: a climate externality, modeled following Heutel (2012), and financial frictions in the banking sector, modeled following Gertler and Karadi (2011). The economy is composed of households, financial intermediaries (i.e. banks), the government, and two types of non-financial firms: (i) goods-producing firms that operate in “brown” and “green” sectors; and (ii) capital-goods firms producing sector-specific capital subject to investment adjustment costs. Households consume "brown" and "green" goods, supply labor to the goods-producing firms and save in the form of bank deposits. Banks combine the deposits with their own net worth to extend credit to non-financial firms in "green" and "brown" sectors. The non-financial firms in turn hire labor and use bank credit to obtain capital. Finally, the government implements climate and macroprudential policies.

We start our simulations from a steady state with a carbon tax of \$10 per ton of CO_2, corresponding to the net effective tax rate in 2021 in the United States (OECD 2022). We then consider potential sources of transition risk, each modeled as a permanent shock, and evaluate the response of economic activity and financial distress. These five sources of transition risk fall into two categories. First we consider three policy-driven shocks: an increase in the carbon tax, a subsidy to emission abatement, and a subsidy to green producers. Second we consider two preference shocks: an increase in consumers' preferences towards green consumption goods, and an increase in investors' preferences towards green asset holding. Along with these shocks, we introduce macroprudential policies, which we model as taxes or subsidies on bank assets that could be differentiated between brown and green assets. In the following subsections, we introduce these shocks and the key model features that are relevant for the transmission and propagation of the shocks, and then we describe the financial frictions plaguing the banking sector and our macroprudential policies.

2.1 Policy-driven shocks

We simulate three distinct climate policies. First, in comparison to the social cost of carbon (Bistline et al. 2023), the \$10 per ton of CO_2 carbon tax is low, and the government might exogenously decide to increase it to reduce emissions. Yet, policies in the United States introduced under the Biden administration advocate for subsidies to promote a cleaner economy. Therefore, we second simulate the introduction of a subsidy for emission abatement costs. Third, we consider the possibility of providing these subsidies directly to green producers, thereby enhancing their marginal revenues.

2.1.1 Carbon tax

As in much of the E-DSGE literature, pollution is a by-product of brown-sector production, but green firms do not pollute. Brown firms can engage in abatement at some endogenous cost. Formally, emissions induced by firms operating in the brown sector are given by

$$e_t = (1 - \mu_t)\, Y_t^b. \tag{1}$$

where μ_t denotes the fraction of emissions abated and Y_t^b is output. The government imposes a time-varying tax τ_t^e on firms' emissions. An increase in this tax increases brown firms' costs by $\tau_t^e e_t$, reducing their profit. (Equation (A.36) in the Appendix gives the brown firms' profit function.)

2.1.2 Abatement subsidy

If firms decide to abate emissions, they face an abatement cost of Z_t, paid in units of their output. We model abatement cost following Nordhaus (2008) and much of the E-DSGE literature (see again Annicchiarico et al. 2021 for a review). We introduce the possibility that the government subsidizes this cost at rate τ_t^z, so that the total abatement cost Z_t is:

$$Z_t = (1 - \tau_t^z)\theta_1(\mu_t)^{\theta_2} Y_t^b. \tag{2}$$

where μ_t again is the fraction of emissions abated, and θ_1 and θ_2 are parameters describing the abatement cost function. The policymaker may have an incentive to subsidize firms' abatement efforts since domestic emissions contribute to the pollution stock in the atmosphere and hence, to climate damages – the effect not internalized by individual firms. Subsidies to abatement became increasingly popular among policymakers in various jurisdictions during the early 2020s, and their use may be justifiable on political economy grounds. There are various options to model subsidies for abatement. For instance, one can interpret τ_t^z as a subsidy for "grey" technologies, reducing the emissions per unit of pollutant production (see, for example, Dechezleprêtre et al. 2013). The introduction of this type of subsidy corresponds to a permanent increase in τ_t^z, from 0 to a positive value which makes it less costly for firms to abate their emissions.

2.1.3 Green producer subsidy

The government might subsidize green producers' marginal revenues to promote economic activity in the green sector and, thereby, encourage the transition to a low-carbon economy. This subsidy τ_t^g directly affects the green producers' revenues: $(1+\tau_t^g)p_t^g Y_t^g$, where p_t^g is their output price and Y_t^g their output quantity. (See equation (A.40) in the Appendix for the green firm profit function.)

The optimality conditions presented in the Appendix (Equations (A.41) and (A.42)) show that *ceteris paribus* the green producer subsidy increases the wage in this sector as well as the returns on green assets. The green subsidy can potentially trigger brown-asset stranding and transition risk. Indeed, the no-arbitrage condition (equation (8) below) shows that an increase in the expected return on green assets must be accompanied by an increase in the required return on brown assets, potentially leading to credit rationing for brown firms. Additionally, the wage increase might divert the labor force from the brown sector.

2.2 Preference shocks

On top of these policy-driven shocks, the transition to a low-carbon economy can occur outside of the government's control because of changes in consumers' and investors' preferences.

For example, Bénabou and Tirole (2010) point out that through “individual and corporate social responsibility,” agents can adopt a “pro-social” behavior, favoring green consumption or green asset holdings for non-pecuniary reasons. We abstract from precise motives behind these preference changes and instead assess whether they constitute a source of transition risk.

2.2.1 Changes in consumers' preferences

Households derive utility by consuming a consumption basket composed of a green consumption good (C_t^g) and a brown consumption good (C_t^b). These goods are bundled into an aggregate C_t with a constant elasticity of substitution (CES) aggregator, reflecting imperfect substitutability:

$$C_t = \left[(\pi_t^b)^{\frac{1}{\rho_c}} (C_t^b)^{\frac{\rho_c - 1}{\rho_c}} + (1 - \pi_t^b)^{\frac{1}{\rho_c}} (C_t^g)^{\frac{\rho_c - 1}{\rho_c}} \right]^{\frac{\rho_c}{\rho_c - 1}} \tag{3}$$

where $\rho_c > 0$ is the elasticity of substitution parameter, and π_t^b is the weight on the brown good in the aggregate consumption basket. This weight is exogenously time-varying. We model the consumer preference shock as an exogenous decrease in this brown weight π_t^b. The cost minimization derived in Appendix A leads to the following demand shares:

$$C_t^b = \pi_t^b C_t (p_t^b)^{-\rho_c} \tag{4}$$

$$C_t^g = (1 - \pi_t^b) C_t (p_t^g)^{-\rho_c} \tag{5}$$

Therefore, a preference shift favoring the green consumption good (an increase in π_t^b) leads to higher demand share for this good. It diverts the consumer from brown consumption, affecting its production and asset prices, potentially generating a shock for the financial system.

2.2.2 Changes in investors' preferences

To describe this preference shock, we present key equations from the model related to the investors' decisions. (Section A.2 of the Appendix fully characterizes the banking sector.)

As in Gertler and Kiyotaki (2010), due to an agency problem between banks and depositors, a banker might divert a fraction κ of its funds away from the bank. Its funds are given by $Q_t^b S_{j,t}^b + Q_t^g S_{j,t}^g$, where Q_t^b and Q_t^g denote brown and green asset prices and S_{jt}^b and S_{jt}^g denote brown and green asset quantities held by an individual banker j.

We denote by $V_{j,t}$ the continuation value of the bank at the end of period t, measuring the present discounted value of future profits from operating honestly. An incentive constraint must hold, reflecting both the incentive for the banker to operate honestly and the shareholders' preferences for each type of asset. Households, who are depositors and banks' shareholders, are willing to lend to the bank only if the continuation value of the bank at the end of period t is larger than the gains from diverting funds, weighted by the constraint on asset holding:

$$V_{j,t} \geq \kappa(\kappa_t^b Q_t^b S_{j,t}^b + \kappa_t^g Q_t^g S_{j,t}^g). \tag{6}$$

Here κ_t^g and κ_t^b are time-varying weights that capture banks' lenders preferences for green and brown asset holdings. In the pre-shock steady state, $\bar{\kappa}^g = \bar{\kappa}^b = 1$, and the incentive constraint boils down to Gertler and Kiyotaki (2010)'s framework, but with two symmetric types of assets. Our incentive constraint limits banks' ability to purchase assets in each sector and allows the agency problem to be asymmetric across assets, reflecting investors' preferences. A higher weight κ_t^b means that it is more complicated for banks to obtain funds from the households if it buys assets from sector b, and likewise for κ_t^g. These weights allow us to introduce another potential source of transition risk. We model a preference change that favors green assets as a relaxed constraint for green asset holdings, i.e. an exogenous decrease in κ_t^g.

2.3 Financial frictions and macroprudential policy

The financial frictions summarized above are central to our model. They imply that the health of the banking sector, as measured by banks' net worth, determines the availability of credit and the level of economic activity. In Appendix A we show that the solution to the banks' maximization problem, which is subject to the incentive constraint (6), implies the following aggregate leverage constraint for the banking sector:

$$\kappa_t^b Q_t^b S_t^b + \kappa_t^g Q_t^g S_t^g = \frac{\varphi_t}{\kappa} N_t. \tag{7}$$

This is the key equation describing the financial frictions; it links financial sector stability to the aggregate supply of credit. It states that banks' ability to finance the economy (total capital available, left-hand side) is limited by their net worth (N_t, right-hand side). It is limited in an inefficient way, and this leverage constraint would not appear in a model with frictionless financial intermediaries. The variable φ_t is a function of several banking sector parameters. Shocks to the economy that impose asset losses in the banking sector can be amplified through inefficient fluctuations in banks' net worth as banks do not internalize how their private decisions affect the aggregate economy.

The presence of such externalities creates rationale for financial regulators to introduce macroprudential policy ensuring the stability of the financial system in response to shocks. We model macroprudential policy as taxes or subsidies on bank assets, which can be differentially applied to brown and green assets. For example, we model "green-supporting" macroprudential policy as a subsidy to green asset holdings and "brown-penalizing" macroprudential policy as a tax on brown asset holdings. We stress that the purpose of this differentiated macroprudential policy is not directly to achieve any particular climate goal, but rather to ensure macroeconomic stability in the face of some other climate policy or preference shock. It is thus consistent with the existing mandate of central banks.

To understand how this macroprudential policy works, consider a no-arbitrage condition satisfied by the banks' optimal portfolio choice (derived in the Appendix):

$$\frac{1}{\kappa_t^b}\mathbb{E}_t\left\{\Omega_{t+1}\left[R_{k,t+1}^b-\left(1+\tau^b\right)R_t\right]\right\}=\frac{1}{\kappa_t^g}\mathbb{E}_t\left\{\Omega_{t+1}\left[R_{k,t+1}^g-\left(1+\tau^g\right)R_t\right]\right\}, \tag{8}$$

where Ω_{t+1} is the bankers' effective stochastic discount factor, R_t is the riskless rate of return, and $R_{k,t+1}^b$ and $R_{k,t+1}^g$ are the assets' gross rates of return. The macroprudential policies are τ^b and τ^g, the taxes (or subsidies, if negative) on brown and green assets.[2] This no-arbitrage condition stipulates that the expected discounted returns on both green and brown assets held by banks, factoring in investors' preferences and the macroprudential tax imposed on each asset type, must be equal. The equation implies that through macroprudental policy, the financial regulator can alter the relative attractiveness of brown versus green assets for banks. A "brown-penalizing" macroprudential policy would levy a tax on brown assets (positive τ^b), decreasing the expected excess return on brown loans relative to green. This would encourage banks to shift their portfolio away from brown and towards green assets. Likewise for a "green-supporting" policy (negative τ^g).

Modeling green macroprudential policy as taxes or subsidies on banks' assets is consistent with Carattini et al. (2023). Our taxes and subsidies represent, in spirit and in a tractable way, differentiated capital requirements, as they have been modeled explicitly elsewhere in the literature.

2.4 Calibration

We calibrate the model parameters based on the U.S. economy. The initial weight of brown consumption goods in the total consumption basket, π_t^b, is equal to one-third. In addition, the initial weights of the constraint on brown and green asset holding, κ_t^b and κ_t^g are set at

[2] We do not model time-varying macroprudential policy so do not index these taxes by t.

1. The other parameters fall into three categories: real business cycle (RBC) parameters, environmental parameters, and parameters related to financial frictions. We relegate a full description of our calibration strategy to Appendix C; Table 1 reports the values of the key parameters. The model is simulated and solved using Dynare.

3 Results

We simulate an economy where there is already a moderate carbon tax ($10 per ton of CO2) in the initial pre-shock steady state but no other policy ($\tau^b = \tau^g = \tau_t^z = \tau_t^y = 0$).

We first simulate the shocks representing our potential sources of transition risk occuring in isolation. We calibrate the magnitude of each shock such that, after the transition to the new steady state, emissions decrease by 5%. However, the green producer subsidy actually triggers an increase in emissions, as we will show below. For this shock, since we cannot calibrate to a 5% emissions decrease, we simulate the introduction of a 5% subsidy for green firms, in line with the concept of the Inflation Reduction Act.[3] First we simulate the three policy-driven shocks: the carbon tax increase (subsection 3.1.1), the abatement subsidy (subsection 3.1.2), and the green producer subsidy (subsection 3.1.3). Second, we simulate the two preference shocks: consumers favoring green consumption goods (subsection 3.2.1) and investors favoring green assets (subsection 3.2.2). In each case, we conduct a "reverse climate stress test," in which we calculate the magnitude of the shock that would be needed to cause an immediate decrease in aggregate output of a given magnitude, namely 1%.

We next examine risk compounding by simulating the co-occurrence of shocks hitting the economy simultaneously (subsections 3.3.1, 3.3.2 and 3.3.3). Finally, we assess how the economy reacts if it is hit by these shocks during a recession caused by a negative total factor productivity shock (subsection 3.3.4).

[3] https://www.whitehouse.gov/wp-content/uploads/2022/12/Inflation-Reduction-Act-Guidebook.pdf (last accessed, September 10, 2024).

Starting from the baseline steady state, the economy is surprised in quarter 5 by these exogenous and permanent shocks. We focus on the transition dynamics (comparisons of the new and old deterministic steady states are presented in the Appendix) and assume that the economy has perfect foresight about its future path after the shocks are revealed.

We gauge the role of the financial sector in transmitting transition risk by comparing our model's results to results from a model with no financial sector and thus, no financial frictions[4]. To assess the policy response to these potential sources of transition risks, we analyze the effectiveness of macroprudential policy in mitigating them. To this end, before the occurrence of these shocks, the policymaker implements a macroprudential policy to ensure the resilience of the financial system.

3.1 Policy-driven shocks

We simulate three types of climate policies reflecting potential policy options.

3.1.1 Carbon tax shock

The introduction of carbon pricing as a source of transition risk has been analyzed by Carattini et al. (2023) and Diluiso et al. (2021). Though our results here are not novel and are consistent with the prior literature, we begin with these simulation results to provide a baseline with which to compare our other policy shock simulations. We simulate the following increase in the carbon price: starting from an initial value at \$10 per ton of CO_2, the government exogenously decides to increase carbon pricing to cut emissions by 5%, increasing τ_t and, therefore, the marginal cost faced by the dirty sector. We report in Appendix D.1 the deterministic steady states with and without financial frictions, and with and without macroprudential policy, though here in the main text we focus on the transition dynamics.

[4] In this case, households lend capital directly to producing firms, and so the model is frictionless.

Figure 1 plots the simulation results following the carbon tax increase under three scenarios: the dashed lines represent a model without financial frictions, the solid lines report the model with financial frictions but no macroprudential policy, and the dotted lines represent the model with financial frictions and an ex-ante macroprudential policy. We present several outcome variables across panels (a) through (h). Each simulation starts in the steady state of the given model and variables are expressed in percentage deviation from their initial steady state.

With an increase in the carbon tax, emissions are more costly and therefore immediately fall, both with and without financial frictions (Panel (a)). These higher costs trigger a decrease in the production of brown goods and the demand for brown capital (Panel (f)), inducing, in turn, a decrease in the price of brown assets (Panel (h)). The lower price of brown assets translates into equity losses for the banks, whose net worth quickly declines (Panel (d)). With financial frictions (solid lines), the economic activity is determined by banks' ability to issue new loans. Following this shock on banks' net worth, banks tighten the supply of credit, negatively affecting the green sector, as evidenced by the initial slight decrease in green capital (Panel (e)) and the price of green assets (Panel (g)). The credit crunch triggers aggregate investment (Panel (b)) and output (Panel (c)) losses. Therefore, an increase in the carbon tax, even of small magnitude, constitutes a source of transition risk, characterized by a recession and a decrease in banks' net worth.

In the absence of financial frictions (red dashed lines), households lend directly to the firms without any agency problem. Therefore, in response to the higher carbon tax, households can easily divert lending away from the less profitable brown firms, whose demand for capital decreases (Panel (f)), and towards the green firms, leading to an increase in green investment (Panel (e)). The decline in economic activity is thus only driven by the lower production in the brown sector and not by additional credit crunch. As a result, in this scenario, aggregate investment and output fall by less as capital smoothly reallocates across sectors.

We now investigate the effect of macroprudential policy in addressing this source of transition risk. The macroprudential tax-and-subsidy policy is targeted at reducing the banks' exposure to brown assets from the baseline 42% to 30%[5]. With the macroprudential policy in place, the banking sector experiences milder equity losses (Panel (d)). Consequently, credit supply is less disrupted and aggregate investment and output fall less (Panels (b) and (c)). The macroprudential policy thus mitigates this source of transition risk, consistent with the previous literature (e.g., Carattini et al. 2023).

For our reverse climate stress test, we note that an increase in the carbon tax, that permanently reduces emissions by 5%, decreases output by only 0.03% in the quarter following the shock. We calculate here how large the shock would have to be to cause a 1% decrease in economic activity. A recession characterized by a 1% decrease in economic activity on impact would be triggered by an increase in the carbon tax from \$10 to \$14.63 per ton of CO_2. Such tax would achieve a 19% decrease in CO_2 emissions.

3.1.2 Abatement subsidy

We simulate the scenario in which the government introduces a permanent subsidy (τ_t^z) to firms' abatement spending in order to reduce the steady-state emissions by 5%. The subsidy lowers the brown firms' marginal cost, stimulating their production. However, the subsidy being financed in a lump-sum manner, also decreases the revenues of the households, affecting the consumption demand. Appendix D.2 compares the deterministic steady states across different policy scenarios and with and without financial frictions.

Figure 2 plots the transitiornal dynamics of the key variables following a surprise introduction of the permanent abatement subsidy, without financial frictions (dashed lines), with financial frictions and no macroprudential policy (solid line), and with financial frictions and ex-ante macroprudential policy (dotted lines).

When the government subsidizes abatement, emissions immediately decrease as it is less

[5]This is achieved by setting $\tau^b = -\tau^g = 0.0047$.

costly to abate emissions (Panel (a)). As shown by the subsequent panels, this shock does not lead to the realization of transition risk: aggregate investment, output, and banks' net worth all slightly increase without macroprudential policy. Indeed, the decrease in emissions is not driven by a decrease in the production of polluting firms, which rather increases. This increase in the production of the brown good is associated with an increase in brown capital depicted in Panel (f) and explained by lower marginal cost induced by the subsidy. As the brown sector expands, the price of brown assets increases (Panel (h)). Through the substitution effect between green and brown goods, as the brown sector expands, the green sector slightly declines, as depicted by the lower green capital (Panel (e)) and a decrease in the price of green assets (Panel (g)).

In the presence of ex-ante macroprudential policy, the cost of holding brown assets is higher, making financial intermediaries less exposed to these assets. Conversely, they are more exposed to green assets, whose price decreases, triggering a slight decrease in banks' net worth (Panel (d)). In this scenario, therefore, macroprudential policy, by diverting the banking sector from the expanding sector, slows down the expansion in aggregate economic activity.

Overall, subsidizing abatement represents a small stimulus characterized by a slight increase in economic activity. Consequently, a recession would be triggered if the government *taxed* abatement. However, given the negligible impact of this policy on aggregate output, there is no reasonable level of tax that would trigger a 1% recession on impact, and therefore we omit a reverse climate stress test for this policy.

3.1.3 Green producer subsidy

This policy can have two opposite effects. By favoring the green sector, subsidies can shift the resources of the economy towards this sector. If the economy moves away from the brown sector, the brown assets might face asset stranding, affecting the financial sector and generating transition risk. However, depending on the calibration of deep parameters (in particular, the substitution elasticity between labor hours and between green and brown consumption goods), through general equilibrium effects, the introduction of this subsidy can also benefit the brown sector and, consequently, the whole economy. To evaluate which effect dominates, Appendix D.3 reports the deterministic steady-states before and after the introduction of the subsidy. This reveals that in the long run, the policy benefits the brown sector as well, triggering an *increase* in emissions in the new steady state. Therefore, for this policy, we do not target a 5% reduction in emissions but instead simulate a 5% subsidy.

Figure 3 plots the trajectory of the main variables of interest before and in the quarters following the introduction of the subsidy. Dashed lines represent the economy without financial frictions, solid lines represent the economy with financial frictions but no macroprudential policy, and dotted lines represent the economy with financial frictions and ex-ante macroprudential policy.

Given our calibration, subsidizing green producers favors the green sector (as evidenced by the increase in green production and capital in Panels (e) and (g)). Through the substitution effect, the expansion of the green sector triggers a decrease in brown production and in brown capital (Panels (f) and (h), respectively). As the expansion of the green sector is more important than the contraction of the dirty one (in particular in the absence of financial frictions), on aggregate, output, investment, and banks' net worth increase (Panels (b), (c) and (d)), highlighting that this subsidy does not constitute a source of transition risk. In the transition reported here, emissions decrease due to the contraction of the dirty sector. However, in the long run (as demonstrated by the steady-state results reported in Appendix D.3), the increase in banks' net worth stimulates the economy, increasing brown production and emissions.

Comparing the solid with the dashed lines showcases the important role of financial frictions in shaping the trajectory of the economy. Without financial frictions, the shrinking of the brown sector is accentuated as households reallocate their resources to the expanding green sector(the higher decrease in production and capital, Panels (f) and (h)). It triggers a quicker and sharper decrease in emissions (Panel (a)). In this scenario, the increase in investment and output is smaller (Panels (b) and (c)) due to the contraction in the brown sector. Turning to the dotted lines, the macroprudential policies, by favoring asset holdings in the expanding sector (green), lead to larger increases in banks' net worth (Panel (d)). The latter effect encourages loan supply to both sectors, slightly mitigating the drop in brown firms' production (Panel (f)) and capital (Panel (h)). Consequently, aggregate investment (Panel (b)) and output (Panel (c)) expand more with the macroprudential policy.

For our reverse climate stress test, we seek to find the subsidy level that would generate a recession characterized by a decline in economic activity of the order of 1% on impact. Since the subsidy triggers an expansion, such a recession would be achieved by a 3.3072% tax on green producers' marginal revenues.

3.2 Preference shocks

3.2.1 Changes in consumers' preferences

We simulate an exogenous and permanent increase in the share of green consumption goods in the household's consumption basket such that emissions decrease by 5%. Appendix D.4 reports the deterministic steady state and the implied values of key variables under three scenarios (no financial frictions, financial frictions without macroprudential policy, and financial frictions with macroprudential policies).

Figure 4 plots the response of the main variables of interest in response to the consumers' preference shock. Again, dashed lines are with no financial frictions, solid lines are with financial frictions but no macroprudential policy, and dotted lines are with financial frictions and macroprudential policy.

The 5% decrease in emissions is reached when the weight of green consumption goods in households' consumption basket increases by 4.3%. In response to this 4.3% increase, the share of green consumption goods immediately increases by more than 2%. Due to imperfect substitutability between green and brown consumption goods, the magnitude of the increase in the share is lower than the magnitude of the increase in the weight. As consumers reduce their demand for brown goods, their production falls, leading to a decrease in emissions (Panel (a)). This decrease in brown production is associated with a decrease in brown capital (Panel (f)) and with a fall in brown asset prices (Panel (h)). The increase in the price of green assets (Panel (g)) does not compensate for the asset devaluation in the brown sector, resulting in a decrease in banks' net worth (Panel (d)). As a result, banks tighten the supply of loans, generating a drop in aggregate investment and output. Panels (b) and (c) demonstrate that this preference shock constitutes a source of transition risk. An increase in the weight of green consumption goods leads to a decrease in banks' net worth and a slowdown in economic activity.

In the absence of financial frictions, the decrease in brown capital is lower and the increase in green capital is higher (Panels (f) and (e), respectively). As a result, financial frictions lead bigger declines in aggregate investment and output (Panels (b) and (c)) compared to the frictionless economy.

Comparing the solid and dotted lines, macroprudential policy mitigates the recessionary effect of this source of transition risk. The decreases in banks' net worth, aggregate investment, and output are lower. With the ex-ante policy, the banking sector moves away earlier from brown assets and therefore experiences smaller equity losses.

We conduct a reverse climate stress test by identifying the value of the shock that would generate a 1% decrease in economic activity on impact. This recession would be reached with a 2.98% increase in the preference for green goods.

3.2.2 Changes in investors' preferences

We now assess if investor preference shocks lead to transition risk. Starting from a pre-shock steady state where the weights of green and brown assets in the financial intermediaries' portfolio are both equal to one, we simulate an exogenous change in the weights such that emissions decrease by 5% while the bank leverage ratio is kept constant. This corresponds to an increase in κ_t^b from 1 to 1.88 and a decrease in κ_t^g from 1 to 0.44. From the incentive constraint (equation (6)), the tighter constraint on brown asset holding implies that banks can issue fewer brown loans with the same net worth; likewise, the lower constraint on green asset holding reflects that banks can issue more green loans. Appendix D.5 reports the relevant variables in different deterministic steady states.

Figure 5 plots the responses of the main variables of interest to the investors' preference shock. Solid lines show the dynamics without macroprudential policy, and dotted lines present the dynamics with macroprudential policy. This figure does not include a simulation for the "no financial frictions" case, since in that case there can be no investor preference shocks as we have modeled them.

In response to the shock and without macroprudential policy, brown assets' valuations decline (Panel (h)) as higher κ_t^b implies that investors move away from brown loans, generating a drop in the demand for brown capital (Panel (f)). However, lower value of κ_t^g relaxes the constraint on green loans, increasing the demand for green assets and consequently, in their price (Panel (g)). The impact of this shock on banks' net worth is determined by the post-shock values of κ_t^b and κ_t^g. In this particular scenario, the tightening of brown constraint is quantitatively stronger and banks' net worth declines (Panel (d)), which leads to a slight decrease in aggregate investment on impact. During the transition, however, aggregate investment and output slightly increase, as the expansion of the green sector ultimately dominates the shrinking of the brown sector (Panels (b) and (c)).

The dotted lines indicate that the presence of ex-ante macroprudential policy enhances the expansionary effects of investors' preference shocks. Under the macroprudential policy, the share of green assets is higher in the pre-shock steady state compared to when no such policy is in place. Following the shock, this share further increases, mitigating the drop in banks' net worth (Panel (d)) and, consequently, boosts aggregate investment and output (Panels (b) and (c)). Additionally, the macroprudential policy generates brown asset valuations (Panel (h)) ensuring an increase in banks' net worth (Panel (d)).

The investor preference shock that reduces emissions by 5% has a positive effect on banks' net worth without affecting aggregate output on impact. Therefore, we do not conduct a reverse climate stress test for this shock. Instead, we investigate the size of the preference shock that would trigger a 1% decrease in *net worth* on impact while keeping the leverage ratio constant. This contraction in the banking sector would be generated if the investors' preference shock led to a 0.398% decrease in emissions (corresponding to a decrease of κ_t^g from 1 to 0.87 and an increase of κ_t^b from 1 to 1.17).

For all five shocks, Appendix E presents results from sensitivity analyses with respect to the elasticity of substitution between brown and green consumption.

3.3 Risk compounding

In this section, we allow multiple sources of transition risk to occur simultaneously. In the first three subsections, we simulate the co-occurrence of two of our shocks, and in subsection 3.3.4, we simulate a shock occurring during a recession triggered by an exogenous decrease in total factor productivity.

3.3.1 Two sources of transition risk: Carbon tax and consumer preference shocks

An increase in carbon pricing and a taste shock among consumers constitute two sources of transition risk. How would an economy react if both shocks occurred simultaneously? To answer this question, we assume that in quarter 5, the economy is surprised by an increase in the carbon tax aimed at reducing emissions by 5%, and, on top of that, consumers shift their consumption basket to favor the green good. We report in Figure 6 the dynamics when both shocks hit the economy without ex-ante macroprudential policy (solid lines) and with ex-ante macroprudential policy (dotted lines).

Without macroprudential policy, the solid lines show that this source of compounding risk has an important negative impact on the economy. The consumer preference shock triggers a decrease in brown capital and a devaluation in brown assets (Panels (f) and (h)). The carbon tax shock has similar negative effects on the brown sector. Therefore, when both shocks occur, the decrease in the price of brown assets is even more important (Panel (h)). As a result, the decrease in banks' net worth is magnified, up to 16% (Panel (d)). Consequently, the decrease in aggregate investment and output (Panels (b) and (c)) are even more important.

The dotted lines plot the transition under both shocks in the presence of ex-ante macroprudential policy. As a reminder, macroprudential policy mitigates the effects of each shock occurring in isolation by diverting banks from brown assets (Figures 1 and 4). When both shocks occur simultaneously, Figure 6 shows that macroprudential policy mitigates the recessionary effects of this risk compounding. The decrease in the price of brown assets is lower (Panels (h)) while green assets experience an higher valuation (Panel (g)), ensuring a lower decrease in banks' net worth (Panel (d)) and a lower credit shrinking. As a result, the increase in green capital is higher (Panel (e)), and the decrease in brown capital is lower (Panel (f)), reducing the drop in aggregate investment and output (Panels (b) and (c)).

3.3.2 Two sources of stimulus: Abatement subsidy and green producer subsidy

We now investigate the dynamics of the model when two sources of stimulus, the abatement and green producers' subsidies, are introduced simultaneously. This corresponds to the policy concepts of the Inflation Reduction Act, which was introduced with the aim of applying various tools, in the spirit of industrial policy, favoring the transition to a low-carbon economy. Figure 7 plots the transition dynamics when the government introduces both subsidies without (solid lines) and with (dotted lines) ex-ante macroprudential policy.

As shown by the solid line and exposed in Section 3.1.2, the subsidy to abatement has a limited effect on macroeconomic and financial variables. Consequently, when both shocks occur simultaneously, the response of aggregate investment, aggregate output and banks' net worth (Panels (b), (c) and (d)) are driven by the subsidy on green producers' marginal revenues. However, while the green producers' subsidy triggered an increase in emissions, the abatement subsidy lowers abatement cost, triggering a decrease in aggregate emissions. When both are introduced together, the emissions decrease (Panel (a))).

In terms of policy recommendations, the simultaneous introduction of these subsidies favors the financial system and economic activity (through the green producers' subsidies) while promoting the transition to a low-carbon economy (via the abatement subsidy).

As shown in Section 3.1.3, macroprudential policies allow a higher increase in aggregate investment, output, and banks' net worth when this shock occurs in isolation. Therefore, when both shocks occur simultaneously, an ex-ante macroprudential policy has similar beneficial effects on macroeconomic and financial variables.

3.3.3 Transition risk and stimulus: Consumer and investor preference shocks

Given the growing awareness of climate-related topics, consumers and investors may modify their preferences simultaneously. In this case, one shock on its own was shown to generate transition risk (consumers'), while the other on its own was shown to provide stimulus (producers'). We report in Figure 8 the dynamics of the model when both shocks hit the economy simultaneously, with and without macroprudential policy (dotted and solid lines, respectively).

When both shocks occur simultaneously, the green sector is favored both by the consumers and by the investors. As a consequence, its assets experience an increase in valuation in the quarters following the shocks (Panel (g), dashed lines). In contrast, brown assets become stranded (Panel (h)). On aggregate, without macroprudential policy, banks' net worth decreases, highlighting that both shocks occurring simultaneously result in transition risk, characterized by a recession in the absence of macroprudential policy (aggregate investment and output both decrease, Panels (b) and (c)).

When both shocks co-occur, how effective is macroprudential policy? Figures 4 and 5 show that, when the shocks occur in isolation, macroprudential policy mitigates the recessionary effects of these sources of transition risk. When both shocks occur simultaneously, macroprudential policy proves effective. It amplifies the rise in green asset prices and mitigates the decline in brown asset prices (Panels (g) and (h)), leading to an increase in banks' net worth (Panel (d)). Consequently, with macroprudential policy in place, the financial system is more resilient to shocks beyond the government's control. This leads to an increase in aggregate investment (Panel (b)). However, while the expansion of the green sector is significant, it does not fully offset the decline in the brown sector. On aggregate, output decreases, though the recession is less severe than it would have been without macroprudential policy (Panel (c)).

In these three subsections, we have examined three policy-relevant combinations of shocks occuring simultaneously. We present results from other shock combinations in Appendix F

3.3.4 Transition risk when a recession hits

Finally, we study how our potential sources of transition risk would affect an economy that suddenly faces a recession. We simulate a one-standard-deviation negative shock to aggregate total factor productivity. As in the standard real business cycle models, this shock has recessionary effects through a decrease in aggregate output. On top of that, the economy is hit by our carbon tax policy shock.

Figure 9 plots the transition dynamics. The solid lines correspond to the dynamics of the model without ex-ante macroprudential policy, while dotted lines represent the transition in the presence of this policy.

Without any additional source of transition risk, a decrease in aggregate productivity lowers the realized returns on both green and brown assets, collapsing their prices (Panels (g) and (h)), resulting in a decrease in banks' net worth (Panel (d)), constraining the banking sector and lowering credit supply. This credit crunch decreases both the green and brown capital (Panels (e) and (f), respectively). As in a standard RBC model, TFP shocks therefore conduct to recessionary effects through a decrease in output (Panel (c)) and investment (Panel (b)). As shown in Section 3.1.1, an increase in carbon pricing has the same effects through different mechanisms. Consequently, these effects are magnified in the presence of a TFP shock. In this scenario, this source of transition risk adversely affects financial stability, with an important decrease in net worth of 20% in the quarter where both shocks occur, and a recession characterized by an immediate 1% decrease in aggregate output (Panels (d) and (c), respectively).

We examine whether macroprudential policies can mitigate the effects of this source of risk compounding. Dotted lines show that the presence of a tax-and-subsidy scheme does not prevent the collapse in asset prices (Panels (g) and (h)) and the resulting decrease in banks' net worth (Panel (d)) triggered by the combination of carbon tax and TFP shocks. As a result, the decrease in output is not mitigated (Panel (c)). It suggests that macroprudential policy does not address the transition risk triggered by an increase in carbon pricing when it occurs simultaneously with a recession. Indeed, such policy is not designed to address the recessionary effects of TFP shocks.Instead, the objective of the tax-and-subsidy scheme is to reduce the banking sector's exposure to brown assets. However, because the TFP is common across sectors, a TFP shock affects both the green and the brown sectors in the same fashion, and the dynamics with and without macroprudential policies are therefore the same.

We presented here the dynamics of the economy when it faces a recession simultaneously with an increase in the carbon tax. We report results for each of our other four shocks occurring simultaneously with a recession in Appendix G.

4 Conclusion

The transition to a low-carbon economy might have detrimental impacts on the financial system and economic activity, in the presence of surprise shocks and absent policies aimed at preparing the ground for a shift towards a cleaner economy. Beyond the implementation of a carbon tax, which is the type of shock that has received most attention so far, concerns have been raised about additional sources of transition risk, which we examine systematically. One of them is preference changes, by consumers and investors, over which policymakers may have no control. Additionally, recent policy in both the United States and the European Union included generous subsidies supporting the transition, whose effects on macroeconomic and financial stability had also been neglected so far. Agreements on such large subsidy packages may occur as a surprise, following long periods of gridlock, meeting the criteria for a proper shock. Further, another novelty of our approach is to also consider the compounding of risks. Multiple shocks may occur at the same time, potentially amplifying each other's effects. Similarly, the abovementioned shocks may also occur at the same time that a total factor productivity shock occurs.

In this paper, we develop an environmental DSGE model incorporating financial frictions and a climate externality. We simulate five potential sources of transition risk, which result from changes in policymaking or shifts in preferences among agents. We simulate an increase in the carbon tax, the introduction of subsidies targeting green producers, subsidies for abatement, a preference shock amongst consumers favoring green consumption, and a preference shock amongst investors favoring green asset holding. We show that the increase in the carbon price leads to transition risk, but the two other policy-driven shocks do not. Instead, they trigger a surge in aggregate investment, output, and banks' net worth. However, the shocks occurring outside the control of the government (consumers' and investors' preference shocks) generate transition risk, materialized by asset stranding in the brown sector, and have recessionary effects.

In terms of policy recommendations, our results suggest that several of the shocks that we consider can alone, and even more so when compounded, lead to financial instability. By engaging in reverse climate stress testing, we can identify how large of a shock of each type it takes for a financial recession to emerge. The picture that emerges suggests that ex-ante macroprudential policy in the form of "brown penalizing" and "green supporting" factors largely functions as a policy tool to insulate the economy from transition risk. When it comes to policies such as carbon taxes, governments may have the possibility to phase them in gradually – at the cost of higher greenhouse gas emissions – or substitute them with subsidy schemes – which also implies a trade-off. But preference shocks are outside of a government's control and can occur as a surprise shock. Importantly, macroprudential policy is less effective in the presence of a downturn driven by a total factor productivity shock, so that absent additional policies, several of the shocks that we study would be especially problematic in bad times.

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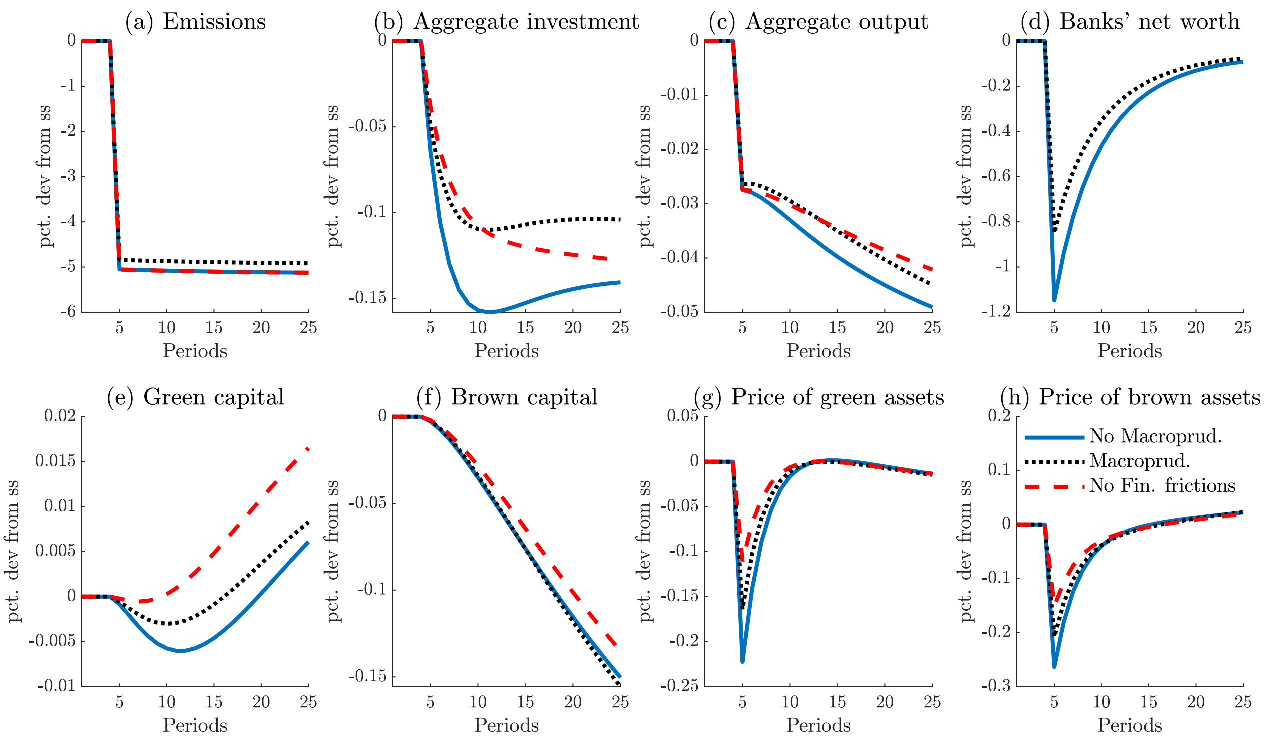
Tables and Figures

Table 1: Calibration

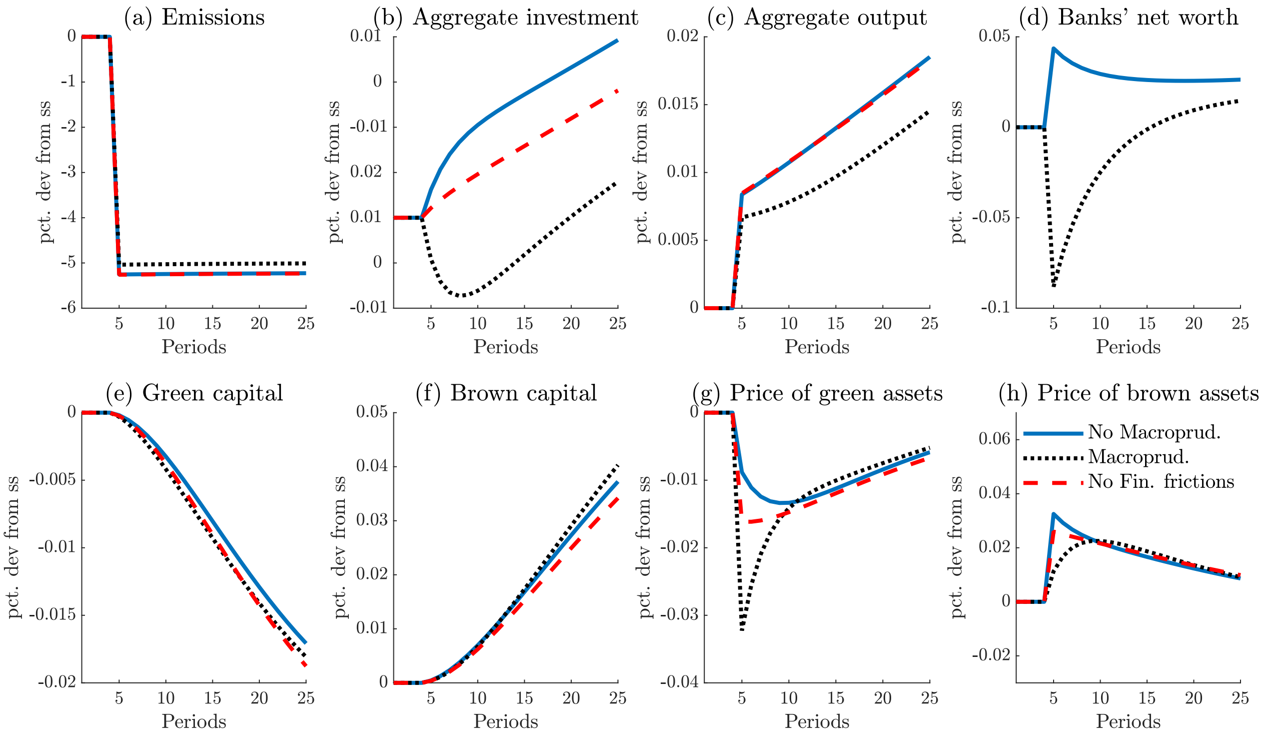
Parameter	Value	Description
RBC parameters		
β	0.9975	Discount factor
η	2	Risk aversion
ξ	1	Frisch elasticity of labor hours
ϖ	8.8893	Labor disutility
ρ_L	1	Intrasectoral CES of labor hours
α^b	0.35	Capital share in 'brown' production
α^g	0.33	Capital share in 'green' production
δ^b, δ^g	0.025	Capital depreciation rate
ϕ^b, ϕ^g	10	Investment adjustment cost
ρ_A^b, ρ_A^g	0.95	Persistence of aggregate TFP shocks
σ_A^b, σ_A^g	0.007	Std. dev. of innovations to TFP
Environmental parameters		
θ_1^b	0.0334	Abatement cost function parameters in the brown sector
θ_2^g	2.6	
d_0	-0.026	Damage function parameters
d_1	3.6613e-5	
d_2	1.4812e-8	
δ_X	0.9965	Pollution decay
e^{row}	2.16905	Emissions in the ROW
ρ_c	2	CES between 'green' and 'brown' consumption goods
Ψ^b	0.5	Emissions-to-output ratio in the brown sector
Ψ^g	0.15	Emissions-to-output ratio in the green sector
Banking sector parameters		
κ	0.3570	Fraction of divertable assets
γ	0.972	Bankers' survival rate
ζ	0.0027	Proportional transfer to new bankers

Figure 1: Carbon pricing



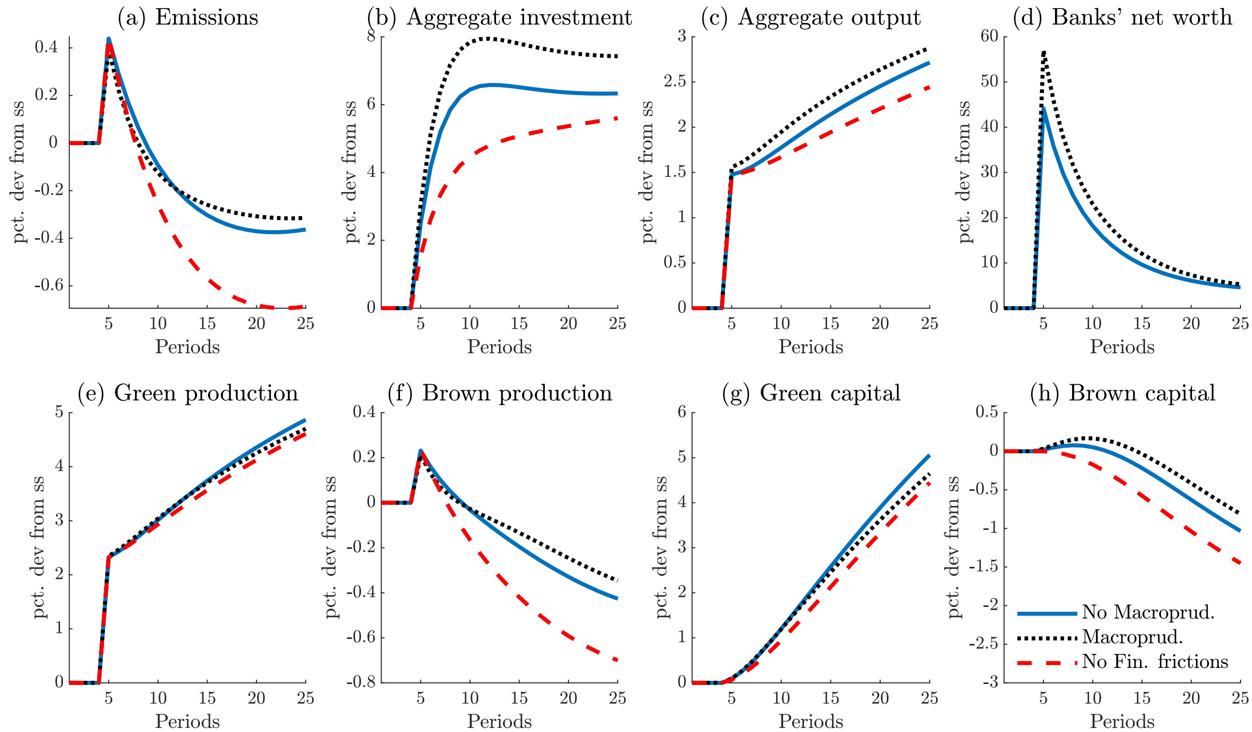
Note: This figure plots the transition dynamics in response to an increase in carbon pricing under three scenarios: (i) No macroprudential policy (solid lines); (ii) with macroprudential policy (dotted lines); (iii) without financial frictions (dashed lines). Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

Figure 2: Abatement subsidies



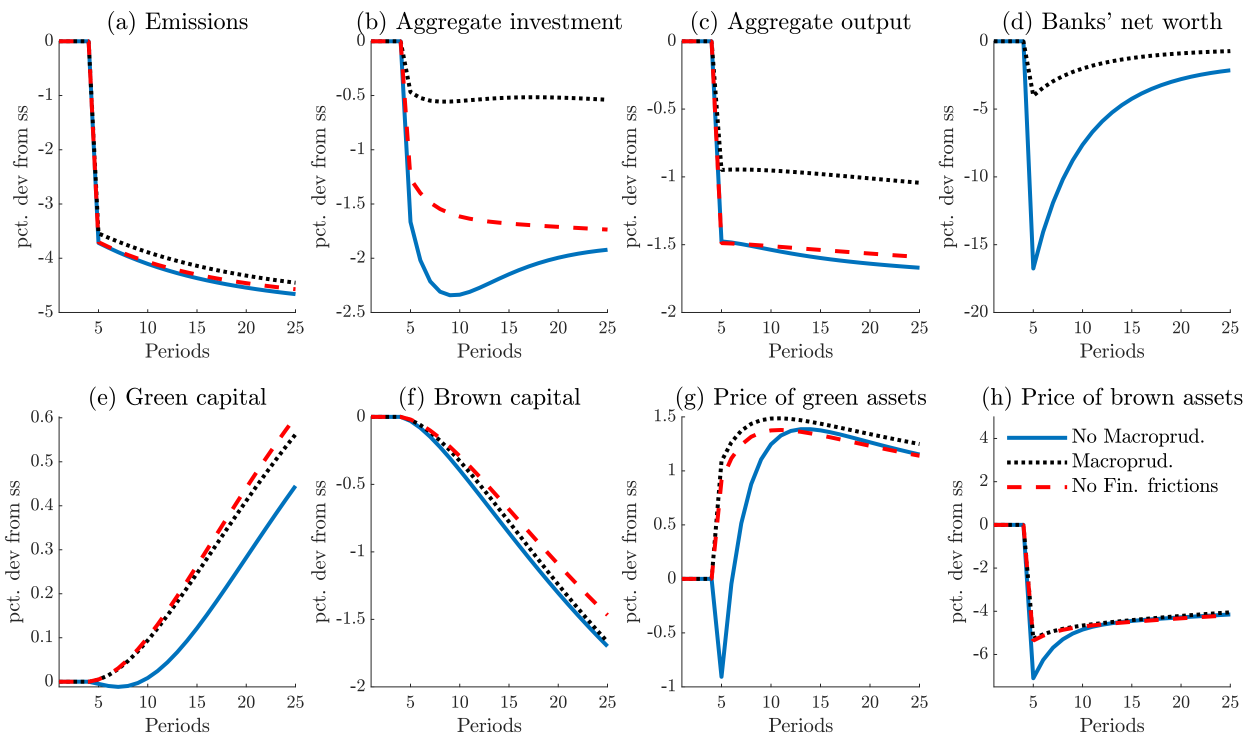
Note: This figure plots the transition dynamics in response to an introduction of abatement subsidies under three scenarios: (i) No macroprudential policy (solid lines); (ii) with macroprudential policy (dotted lines); (iii) without financial frictions (dashed lines). Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

Figure 3: Green producers subsidies



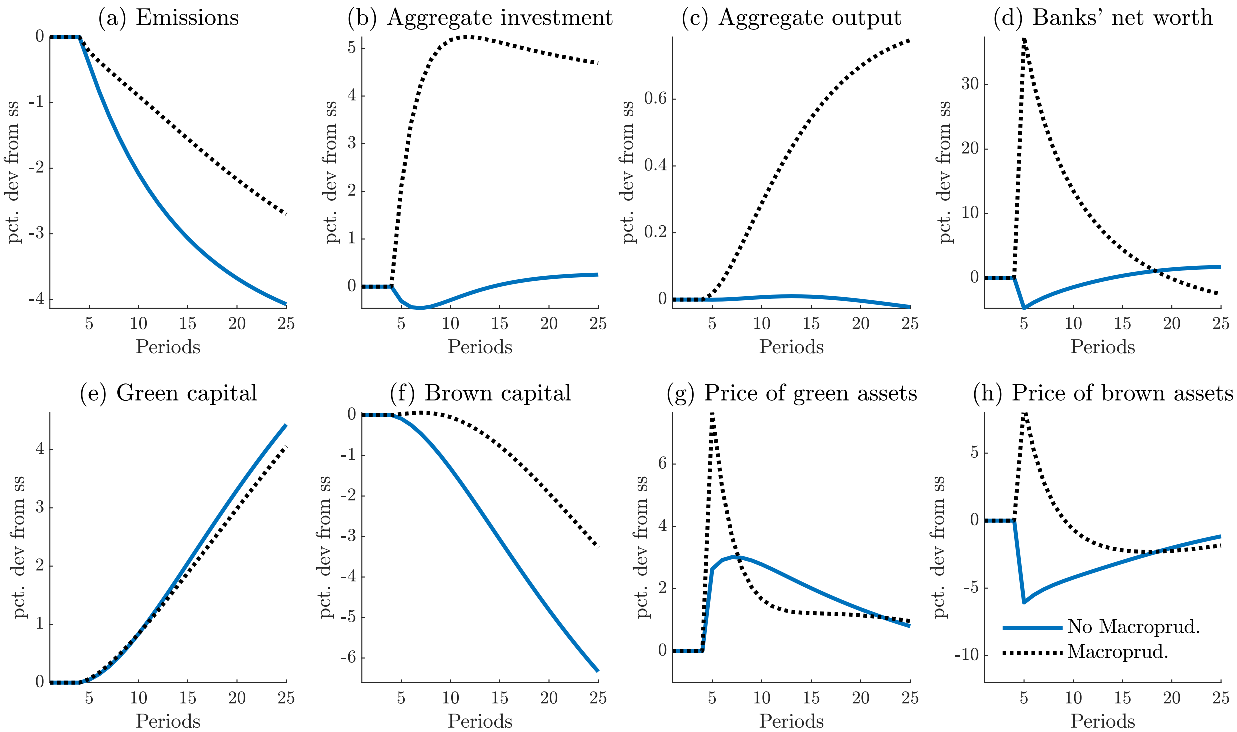
Note: This figure plots the transition dynamics in response to an introduction of subsidies for green producers under three scenarios: (i) No macroprudential policy (solid lines); (ii) with macroprudential policy (dotted lines); (iii) without financial frictions (dashed lines). Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

Figure 4: Consumers' preference shock



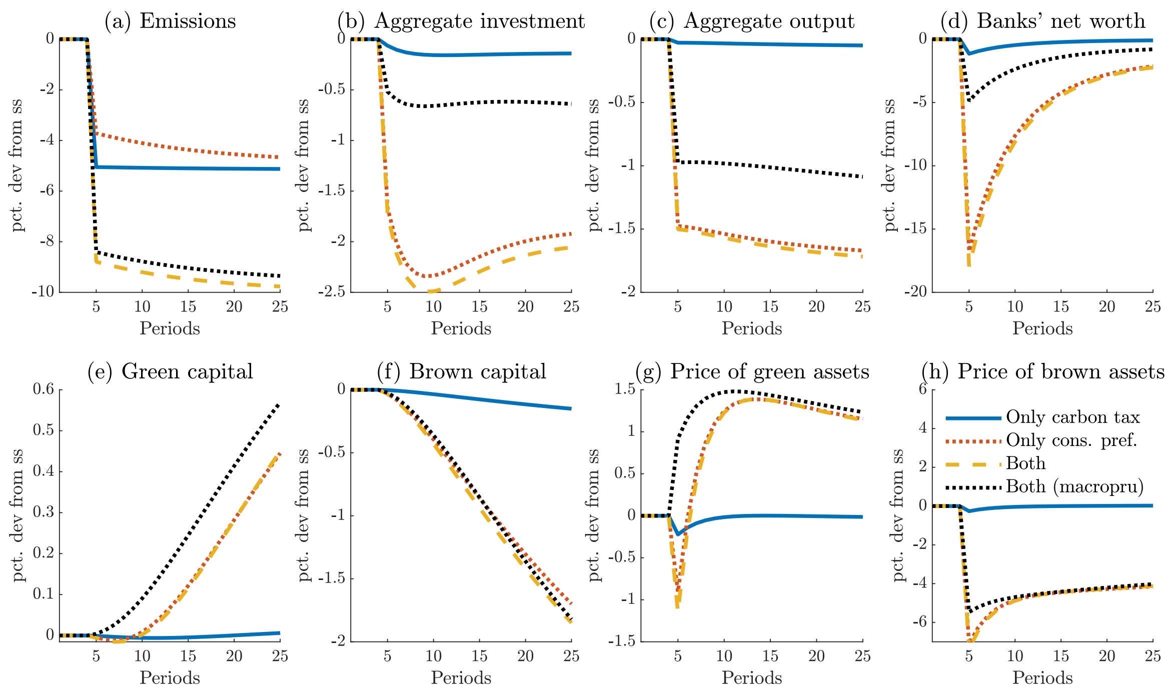
Note: This figure plots the transition dynamics in response to a consumer preference shock under three scenarios: (i) No macroprudential policy (solid lines); (ii) with macroprudential policy (dotted lines); (iii) without financial frictions (dashed lines). Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

Figure 5: Investors' preference shock



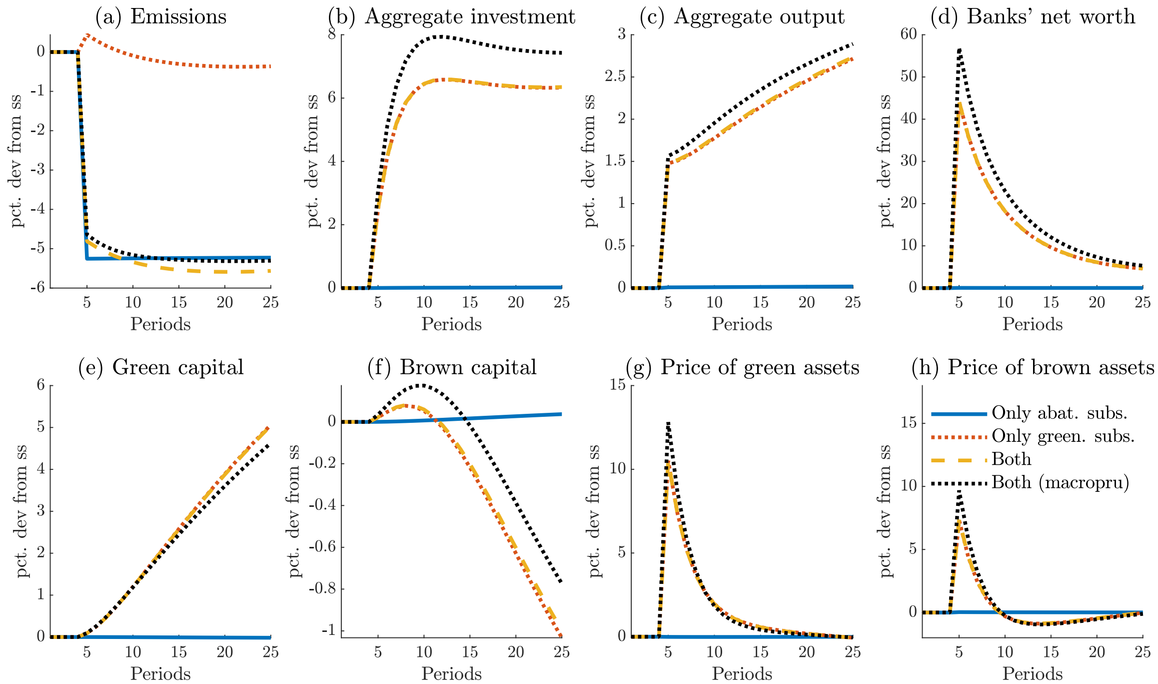
Note: This figure plots the transition dynamics in response to an investor preference shock under two scenarios: (i) No macroprudential policy (solid lines); (ii) with macroprudential policy (dotted lines). Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

Figure 6: Co-occurence of carbon tax shock and consumers' preference shocks



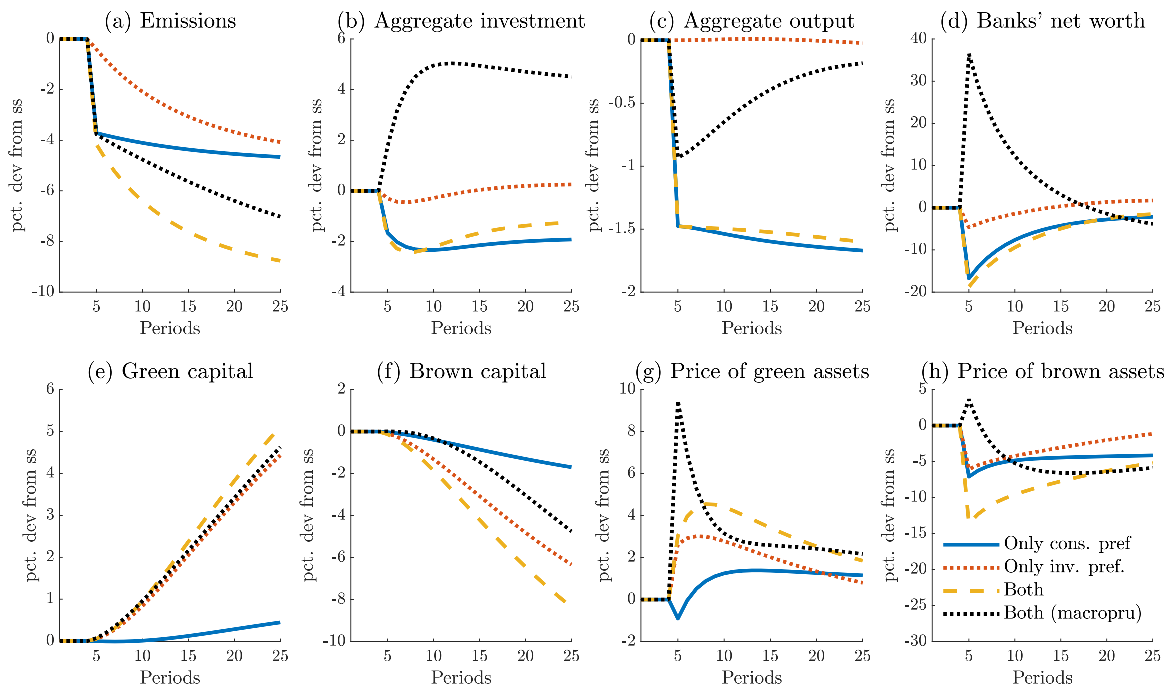
Note: This figure plots the transition dynamics in response to different combinations of shocks to carbon pricing and consumers' preferences under four scenarios: (i) only the carbon tax shock occurs without macroprudential policy (solid lines); (ii) only the consumer preference shock occurs without macroprudential policy (red dotted lines); (iii) both shocks co-occur without macroprudential policy (yellow dashed lines) and (iv) both shocks co-occur with macroprudential policy (black dotted lines). Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

Figure 7: Co-occurence of abatement subsidy and green producers' subsidy



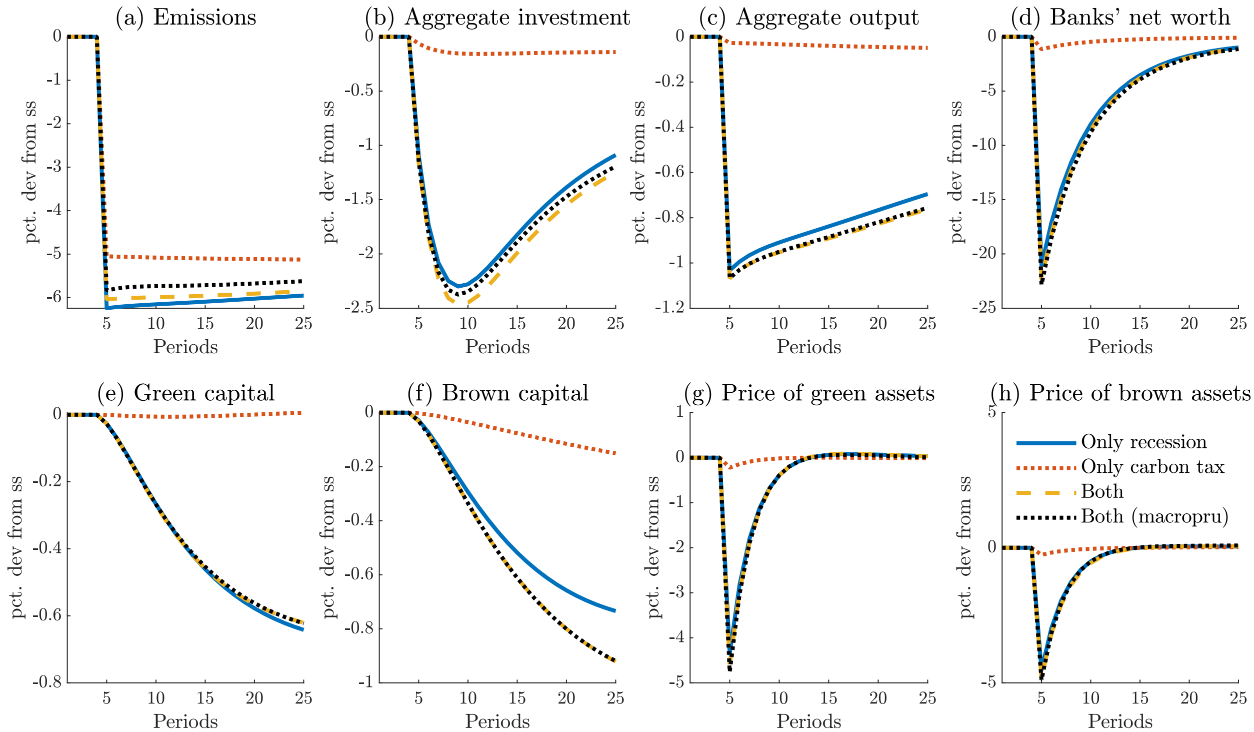
Note: This figure plots the transition dynamics in response to different combinations of shocks to abatement subsidies and green producers' subsidies under four scenarios: (i) only the abatement subsidy shock occurs without macroprudential policy (solid lines); (ii) only the green subsidy shock occurs without macroprudential policy (red dotted lines); (iii) both shocks co-occur without macroprudential policy (yellow dashed lines) and (iv) both shocks co-occur with macroprudential policy (black dotted lines). Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

Figure 8: Co-occurence of consumer and investor preference shocks



Note: This figure plots the transition dynamics to different combinations shocks to consumers' and investors' preferences under four scenarios: (i) only the consumer preference shock occurs without macroprudential policy (solid lines); (ii) only the investor preference shock occurs without macroprudential policy (red dotted lines); (iii) both shocks co-occur without macroprudential policy (yellow dashed lines) and (iv) both shocks co-occur with macroprudential policy (black dotted lines). Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

Figure 9: Carbon tax shock during a recession



<u>Note</u>: This figure plots the transition dynamics in response to different combinations of shocks to carbon pricing and TFP under four scenarios: (i) only the TFP shock occurs without macroprudential policy (solid lines); (ii) only the carbon tax shock occurs without macroprudential policy (red dotted lines); (iii) both shocks co-occur without macroprudential policy (yellow dashed lines) and (iv) both shocks co-occur with macroprudential policy (black dotted lines) Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

Appendix

A Model

A.1 Households

There is a continuum of identical households of length unity, each composed of a continuum of infinitely-living household members. In every period, the representative household is endowed with one unit of time. It consumes and saves through deposits in the financial intermediaries and owes firms producing consumption goods and capital. As in Gertler and Karadi (2011), a fraction $(1-\iota)$ of members are workers, and a fraction ι are bankers. Workers supply labor, either to the green-producing firm or the brown one, and receive a sector-specific wage. Bankers manage a financial intermediary and get dividends. All sources of revenues (wages, dividends, and profits from firm-owning) are returned to the household.

The optimization of the household is a two-stage problem. First, it decides on the consumption allocation between green and brown goods. Then, it maximizes the following lifetime utility:

$$\mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t \frac{1}{1-\eta} \left(C_t - \varpi \frac{\left[\left(L_t^b \right)^{1+\rho_L} + \left(L_t^g \right)^{1+\rho_L} \right]^{\frac{1+\xi}{1+\rho_L}}}{1+\xi} \right)^{1-\eta} \right\}, \tag{A.1}$$

subject to the budget constraint,

$$C_t + D_t = w_t^b L_t^b + w_t^g L_t^g + R_{t-1} D_{t-1} + \Xi_t + \Pi_t + T_t, \tag{A.2}$$

where C_t denotes the consumption basket, which is the numeraire. D_t is bank deposits, L_t^b and L_t^g are sector-specific labor hours, w_t^b and w_t^g are wage rates in brown and green sectors, R_{t-1} is a non-contingent interest rate on bank deposits, Ξ_t are net dividends from banks, Π_t denotes profits from the ownership of non-financial firms, and T_t is a lump-sum transfer from the government. The parameter $\beta \in (0,1)$ is a constant discount factor, $\varpi > 0$ weights the disutility of working, ξ denotes the inverse of the Frisch elasticity of labor, and $\eta > 0$ controls the curvature of the utility function. The specification of labor hours in the utility function $\left(L_t \equiv \left[\left(L_t^b \right)^{1+\rho_L} + \left(L_t^g \right)^{1+\rho_L} \right]^{\frac{1}{1+\rho_L}} \right)$ follows Horvath (2000) and introduces imperfect labor substitutability between green and brown sectors when $\rho_L > 0$.

The consumption basket is composed of a green and a brown consumption good, bundled with a constant elasticity of substitution (CES) aggregator, reflecting the imperfect substitutability between sector consumption goods:

$$C_t = \left[(\pi_t^b)^{\frac{1}{\rho_c}} (C_t^b)^{\frac{\rho_c - 1}{\rho_c}} + (1 - \pi_t^b)^{\frac{1}{\rho_c}} (C_t^g)^{\frac{\rho_c - 1}{\rho_c}} \right]^{\frac{\rho_c}{\rho_c - 1}} \tag{A.3}$$

where $\rho_c > 0$ is the elasticity of substitution parameter, and π_t^b is the weight of the brown good in the consumption basket. This weight is exogenously time-varying. The total cost of the consumption basket is given by:

$$P_t C_t = P_t^g C_t^g + P_t^b C_t^b \tag{A.4}$$

where we normalize P_t, the price of the consumption basket, at one. P_t^b and P_t^g denote the prices of brown and green consumption goods.

The cost-minimization problem leads to the following demand functions for the two types of consumption goods:

$$C_t^b = \pi_t^b C_t (p_t^b)^{-\rho_c} \tag{A.5}$$

$$C_t^g = (1 - \pi_t^b) C_t (p_t^g)^{-\rho_c} \tag{A.6}$$

where $p_t^i \equiv \frac{P_t^i}{P_t}$ is the relative price of good $i = \{g, b\}$.

The second stage of the household's optimization problem consists in choosing consumption C_t, deposits D_t and sector-specific labor supply L_t^g and L_t^b to maximize utility (A.1) subject to the budget constraint (A.2).

Solving for the first-order conditions, households' optimal consumption and labor supply decisions are given by:

$$\mathbb{E}_t \left(M_{t,t+1} R_t \right) = 1, \tag{A.7}$$

$$\varpi L_t^{\xi - \rho_L} \left(L_t^i \right)^{\rho_L} = w_t^i, \quad \text{for } i = \{g, b\}. \tag{A.8}$$

where $M_{t,t+1} \equiv \beta \frac{U_{c,t+1}}{U_{c,t}}$ denotes the household's stochastic discount factor, and $U_{c,t} = \left(C_t - \varpi \frac{L_t^{1+\xi}}{1+\xi} \right)^{-\eta}$ is the marginal utility of consumption.

A.2 Bankers

We model the banking sector following Gertler and Kiyotaki (2010), and enabling it to lend both to the green and the brown firms, claiming sector-specific loans. On the liability side of the balance sheet, each individual banker j receives deposits from the household and holds net worth. On the asset side, it buys securities $S^i_{j,t}$ from sector-i firms, remunerated at market price Q^i_t, $i = \{g, b\}$. We model macroprudential policy as taxes and/or subsidies τ^i_t on the bank's assets, which may also depend on the assets' sector.[6] Therefore, the flow-of-funds constraint in time t is given by:

$$(1 + \tau^b_t) Q^b_t S^b_{j,t} + (1 + \tau^g_t) Q^g_t S^g_{j,t} = D_{j,t} + N_{j,t}. \tag{A.9}$$

Each security is remunerated at the gross rate of returns $R^i_{k,t}$, and the deposits are remunerated at riskless rate R_t. The evolution of the net worth of an individual banker j is thus:

$$N_{j,t+1} = R^b_{k,t+1} Q^b_t S^b_{j,t} + R^g_{k,t+1} Q^g_t S^g_{j,t} - R_t D_{j,t}. \tag{A.10}$$

The financial sector is plagued with financial frictions. We model them following Gertler and Kiyotaki (2010) and assume an agency problem between bankers and their lenders (in our model, the households who save through bank deposits). At each period, after raising deposits and purchasing assets, the banker can choose to divert a fraction κ of its funds away from the bank. In that case, households can liquidate the bank and recover the remaining fraction of assets, $(1 - \kappa)$. The possibility of fund diversion leads households to impose an incentive constraint on banks to operate honestly. Denoting $V_{j,t}$ the continuation value of the bank at the end of period t, this incentive constraint is given by:

$$V_{j,t} \geq \kappa (\kappa^b_t Q^b_t S^b_{j,t} + \kappa^g_t Q^g_t S^g_{j,t}). \tag{A.11}$$

where κ^g_t and κ^b_t are time-varying weights that can be modified in case of a preference shock for green asset holding. This inequality always holds, so in equilibrium, bankers never actually divert funds.

In the household, bankers and workers can switch occupations over time. Therefore, at the end of each period, a banker might become a worker and exit the business with an exogenous probability $1 - \gamma$. Then, it transfers her earnings to the household in the form of dividends.[7] The proportion γ of bankers who stay in the business reinvest all their net worth.

[6] The underlying assumption is that the regulator has sufficient information about bankers' exposure to the green and brown sectors. Hence, a prerequisite for successful green macroprudential policy (as well as climate stress testing) is mandatory disclosure of climate risks (Carattini et al. 2022). Given the expansion of mandatory disclosure, especially when considering both planned and enacted regulations, we consider this assumption plausible in the policy horizon of interest.

[7] The number of bankers that become workers in every period is thus $(1 - \gamma)\,\iota$. To keep the relative proportion of each group fixed over time, we assume that the same number of workers randomly become bankers in every period.

The problem of an individual banker is to choose asset holdings in green and brown production sectors $S^i_{j,t}$, $i = \{g, b\}$ to maximize

$$V_{j,t} = \mathbb{E}_t \left\{ \sum_{\widetilde{\tau}=t+1}^{\infty} (1-\gamma)\, \gamma^{\widetilde{\tau}-t-1} M_{t,\widetilde{\tau}} N_{j,\widetilde{\tau}} \right\}, \tag{A.12}$$

subject to (A.9), (A.10) and (A.18), where $M_{t,\widetilde{\tau}}$ is the banker's stochastic discount factor: $M_{t,\widetilde{\tau}} \equiv \beta^{\widetilde{\tau}-t} \frac{U'_{c,\widetilde{\tau}}}{U'_{c,t}}$.

To solve the bankers' problem, we first assume that the bankers' value function is linear in its net worth:

$$V_{j,t} = \varphi_t N_{j,t} \tag{A.13}$$

Then, we define:

$$\chi^b_t = E_t \left\{ \Omega_{t+1} (R^b_{k,t+1} - (1+\tau^b) R_t \right\} \tag{A.14}$$

$$\chi^g_t = E_t \left\{ \Omega_{t+1} (R^g_{k,t+1} - (1+\tau^g) R_t \right\} \tag{A.15}$$

$$\nu_t = E_t \left\{ \Omega_{t+1} R_t \right\} \tag{A.16}$$

Plugging (A.9) in (A.10) and using equations (A.13) - (A.16), the Bellman rewrites:

$$V_{j,t} = \mathbb{E}_t \left\{ \chi^b_t Q^b_t S^b_t + \chi^g_t Q^g_t S^g_t + \nu_t N_t \right\} \tag{A.17}$$

and the incentive constraint becomes:

$$\mathbb{E}_t \left\{ \chi^b_t Q^b_t S^b_t + \chi^g_t Q^g_t S^g_t + \nu_t N_t \right\} \geq \kappa (\kappa^b_t Q^b_t S^b_{j,t} + \kappa^g_t Q^g_t S^g_{j,t}) \tag{A.18}$$

The banker's problem is to choose S^g_t and S^b_t to maximize (A.17) subject to the incentive constraint (A.18).

Denoting λ_t the Lagrange multiplier, the first-order conditions are:

$$\chi^b_t = \lambda_t \kappa \kappa^b_t \tag{A.19}$$

$$\chi^g_t = \lambda_t \kappa \kappa^g_t \tag{A.20}$$

Combining (A.20) with (A.19), we have:

$$\frac{1}{\kappa^b_t} \chi^b_t = \frac{1}{\kappa^g_t} \chi^g_t \tag{A.21}$$

The slackness condition is:

$$\lambda_t \left[\chi_t^b Q_t^b S_{j,t}^b + \chi_t^g Q_t^g S_{j,t}^g + \nu_t N_t - \kappa(\kappa_t^b Q_t^b S_{j,t}^b + \kappa_t^g Q_{j,t}^g S_t^g)\right] = 0 \tag{A.22}$$

where (A.20) yields $\lambda_t = \frac{\chi_t^b}{\kappa\kappa_t^b}$. Therefore, the incentive constraint binds when $\lambda_t > 0$ or when $0 < \chi_t^b < \kappa\kappa_t^b$, which is the case in our model's calibration. When the incentive constraint binds, we have:

$$\kappa_t^b Q_t^b S_{j,t}^b + \kappa_t^g Q_t^g S_{j,t}^g = N_{j,t} \frac{\nu_t}{\kappa - \frac{\chi_t^b}{\kappa_t^b}} \tag{A.23}$$

We verify our conjecture (A.13):

$$V_{j,t} = \frac{\chi_t^b}{\kappa_t^b}\left(\kappa_t^b Q_t^b S_{j,t}^b + \kappa_t^g Q_t^g S_{j,t}^g\right) + \nu_t N_{j,t} \tag{A.24}$$

$$\Rightarrow \varphi_t = \frac{\kappa\kappa_t^b \nu_t}{\kappa\kappa_t^b - \chi_t^b} \tag{A.25}$$

Therefore, an individual bank value is linear in individual net worth,

$$V_{j,t} = \varphi_t N_{j,t}, \tag{A.26}$$

where $\varphi_t \geq 1$ is the time-varying shadow value of a bank's net worth, common across banks.

Combining (A.26) with (A.18), we can express the incentive constraint as

$$N_{j,t} \geq \frac{\kappa}{\varphi_t}(\kappa_t^b Q_t^b S_{j,t}^b + \kappa_t^g Q_t^g S_{j,t}^g). \tag{A.27}$$

To comply with investors' preferences and because of the agency problem, bank's assets cannot exceed a fraction $\frac{\kappa}{\varphi_t}$ of its equity capital. In our calibrated model, this constraint will always bind in the proximity of the steady state

Equation (A.25) shows that the banks' shadow value is common across banks, since κ, κ_t^g, ν_t and χ_t^b are not bank-specific.

Aggregating (A.27) at equality for the whole banking sector and imposing (A.25) yields the leverage constraint of the banking system :

$$\kappa_t^b Q_t^b S_t^b \kappa_t^g + \kappa_t^g Q_t^g S_t^g = \frac{\varphi_t}{\kappa} N_t. \tag{A.28}$$

We close this section by defining the evolution of the banking sector's net worth. Each period, bankers might exit the business and become workers, while workers can become bankers. Exiting bankers are replaced by an equal number of new banks, keeping the proportions ι and $(1-\iota)$ fixed. Each new banker receives a transfer $\frac{\zeta}{1-\gamma}\sum_{i=\{g,b\}} Q_t^i S_t^i$ from the household to start the business. The evolution of the aggregate banking sector is thus given by:

$$N_{t+1} = \gamma \left[\sum_{i=\{g,b\}} R^i_{k,t+1} Q^i_t S^i_t - R_t D_t \right] + \zeta \sum_{i=\{g,b\}} Q^i_t S^i_t, \tag{A.29}$$

and the net dividend payouts to households are

$$\Xi_{t+1} = (1-\gamma) \left[\sum_{i=\{g,b\}} R^i_{k,t+1} Q^i_t S^i_t - R_t D_t \right] - \zeta \sum_{i=\{g,b\}} Q^i_t S^i_t. \tag{A.30}$$

Finally, we define the credit spread as the difference between the expected rate of return on a given type of asset and the risk-free rate, $\text{spread}_t^i \equiv \mathbb{E}_t \left(R^i_{k,t+1} - R_t \right), \ i \in \{b, g\}$.

A.3 Goods-producing firms

The production sector comprises two types of firms that produce sectoral goods, employing sector-specific labor and sector-specific capital. The production of these firms generates byproduct emissions, deteriorating the environment and affecting productivity. The "brown" firm pollutes while the "green" does not. In the absence of a climate policy, firms operating in the brown sector do not internalize the environmental externality, leading to inefficiently high levels of emissions.

A.3.1 Production Technology

Both types of firms use a Cobb-Douglas combination of labor and capital to produce the sectoral consumption good. The stock of pollution in the economy alters the production process as follows:

$$Y_t^i = [1 - d(X_t)] A_t \left(K^i_{t-1} \right)^{\alpha^i} \left(L^i_t \right)^{1-\alpha^i}, \ i \in \{b, g\}. \tag{A.31}$$

where $\alpha^i \in (0,1)$ is the elasticity of output with respect to capital, X_t is the pollution stock in the economy, $d(\cdot) \in (0,1)$ is an increasing damage function, and A_t denotes the aggregate stochastic total factor productivity (TFP) which evolves as follows:

$$\log A_t = \rho_A \log A_{t-1} + \sigma_A \varepsilon_{A,t}, \quad \varepsilon_{A,t} \sim \mathcal{N}(0,1). \tag{A.32}$$

Green and brown consumption goods are imperfect substitutes for each other. In the households' consumption basket (A.3), $\rho_c > 0$ captures the elasticity of substitution between both goods and $\frac{\rho_c}{\rho_c - 1}$ is the constant mark-up charged by monopolistically competitive sectors.

Both sectors are profit-maximizing and set their monopolistic price given the demand function they face, provided in (A.5) and (A.6).

We now turn to the description of the optimization program of each representative good-producing firm. We follow Nordhaus (2008) and Heutel (2012) to specify emissions, abatement cost, and the damage function.

The domestic emissions induced by brown firms are given by:

$$e_t = (1 - \mu_t) Y_t^i. \tag{A.33}$$

If brown firms decide to abate emissions, they face an abatement cost of Z_t, paid in units of their production, which is given by:

$$Z_t = (1 - \tau_t^z)\theta_1 (\mu_t)^{\theta_2} Y_t. \tag{A.34}$$

The pollution stock X_t evolves according to

$$X_t = \delta_X X_{t-1} + e_t^b + e_t^{\text{row}}, \tag{A.35}$$

where e_t^{row} denotes emissions from the rest of the world. The pollution stock affects the production of green and brown consumption goods through the increasing damage function $d(X_t)$.

The brown firm maximizes its profit by choosing labor, capital, and abatement. Its profit corresponds to the difference between its revenues and its costs. The brown firm earns revenue by selling at price p_t^b the production good Y_t^b. In addition, it can sell its undepreciated capital $\left(1 - \delta^b\right) K_t^b$ to capital producers at price Q_{t+1}^b. Regarding its costs, the firm has to pay Z_t to abate emissions. It remunerates the labor force L_t^b at wage w_t^b, and purchases capital K_t^b from capital producers at market price Q_t^b. To this end, it issues claims S_t^b to banks,[8] with a state-contingent return $R_{k,t+1}^b$. In addition, the government imposes a time-varying tax τ_t^e on

[8] Here, $Q_t^b K_t^b = Q_t^b S_t^b$.

firm's emissions.

The time t realized profit of the brown firm is thus:

$$\Pi_t^b = p_t^b Y_t^b - \tau_t^e e_t^b - p_t^b Z_t^b - w_t^b L_t^b - R_{k,t}^b Q_{t-1}^b K_{t-1}^b + \left(1-\delta^b\right) Q_t^b K_{t-1}^b. \tag{A.36}$$

The profit-maximization problem leads to the following first-order conditions for labor $\left(L_t^b\right)$, abatement (μ_t) and capital (K_t^b):

$$w_t^b = \left(1-\alpha^b\right) \frac{Y_t^b}{L_t^b} \left[p_t^b - p_t^b(1-\tau_t^z)\theta_1^b(\mu_t^b)^{\theta_2^b} - \tau_t^e \left(1-\mu_t^b\right)\right], \tag{A.37}$$

$$\tau_t^e = (1-\tau_t^z) p_t^b \theta_1^b \theta_2^b (\mu_t^b)^{\theta_2^b - 1}. \tag{A.38}$$

$$R_{k,t}^b = \frac{\alpha^b \frac{Y_t^b}{K_{t-1}^b} \left[p_t^b - p_t^b(1-\tau_t^z)\theta_1^b(\mu_t^b)^{\theta_2^b} - \tau_t^e \left(1-\mu_t^b\right)\right] + \left(1-\delta^b\right) Q_t^b}{Q_{t-1}^b}. \tag{A.39}$$

Equation (A.38) indicates that brown firms will abate emissions up to the point where the marginal gain of doing so equalizes the marginal cost. The introduction of abatement subsidies lowers the marginal cost of abating, favoring an increase in abatement.

As the brown firm, the representative firm producing the green good purchases green capital K_t^g at price Q_t^g using bank credit. It demands labor L_t^g from workers, remunerated at wage rate w_t^g. The government might subsidize green producers to encourage the transition to a low-carbon economy. The introduction of such a subsidy is modeled by a permanent increase of τ_t^g, from 0 to a positive value.

The profit function of the green sector is given by:

$$\Pi_t^g = (1+\tau_t^g) p_t^g Y_t^g - w_t^g L_t^g - R_{k,t}^g Q_{t-1}^g K_{t-1}^g + (1-\delta^g)\, Q_t^g K_{t-1}^g. \tag{A.40}$$

The cost-minimization leads to the following optimality conditions:

$$w_t^g = (1-\alpha^g)\,(1+\tau_t^g) \frac{Y_t^g}{L_t^g} p_t^g, \tag{A.41}$$

$$R_{k,t}^g = \frac{\alpha^g (1+\tau_t^g) \frac{Y_t^g}{K_{t-1}^g} p_t^g + (1-\delta^g)\, Q_t^g}{Q_{t-1}^g}. \tag{A.42}$$

A.4 Capital producers

There are two types of capital producers, for each type of capital in the economy. Capital is sector-specific and immobile across sectors. In each sector, capital-producing firms are competitive. They face quadratic adjustment costs when producing new capital, introducing endogenous fluctuations in banks' net worth. These adjustment costs are modeled as in Christiano et al. (2005), and paid in units of the corresponding good (firms producing brown capital will pay the adjustment cost in units of brown capital). In each period t, the price of the capital in the economy is Q_t^i, $i = \{g, b\}$.

In each sector, the capital producers solve:

$$\max_{\{I_t^i\}_{i=\{g,b\}}} \mathbb{E}_0 \sum_{t=0}^{\infty} M_{0,t} \sum_{i=\{g,b\}} \left[Q_t^i I_t^i - \left(1 + \frac{\phi^i}{2}\left(\frac{I_t^i}{I_{t-1}^i} - 1\right)^2\right) p_t^i I_t^i \right]. \tag{A.43}$$

where $\phi^i \geq 0$ is a parameter controlling the size of the adjustment cost.

The first-order optimality condition associated with this problem is

$$Q_t^i = p_t^i \left[1 + \frac{\phi^i}{2}\left(\frac{I_t^i}{I_{t-1}^i} - 1\right)^2 + \phi^i \left(\frac{I_t^i}{I_{t-1}^i} - 1\right)\frac{I_t^i}{I_{t-1}^i}\right] - \mathbb{E}_t \left\{ p_{t+1}^i M_{t,t+1} \phi^i \left(\frac{I_{t+1}^i}{I_t^i} - 1\right)\left(\frac{I_{t+1}^i}{I_t^i}\right)^2 \right\}, \quad i = \{g, b\}. \tag{A.44}$$

Sector-specific capital stock evolves according to:

$$K_t^i = \left(1 - \delta^i\right) K_{t-1}^i + I_t^i, \text{ for } i = \{g, b\}, \tag{A.45}$$

where δ^i is the depreciation rate of capital.

A.5 Government

The government simply transfers net revenues to households and finances subsidies in a lump-sum manner:

$$T_t = \tau_t^e e_t + \tau_t^b Q_t^b S_t^b + \tau_t^g Q_t^g S_t^g + \tau_t^g p_t^g Y_t^g - \tau_t^z \theta_1 \mu_t^{\theta_2} Y_t^b. \tag{A.46}$$

A.6 Market Clearing

Market clearing on the green market imposes:

$$p_t^g Y_t^g = p_t^g C_t^g + p_t^g I_t^g + \frac{\phi^g}{2}\left(\frac{I_t^g}{I_{t-1}^g} - 1\right)^2 p_t^g I_t^g \tag{A.47}$$

And on the brown market:

$$p_t^b Y_t^b = p_t^b C_t^b + p_t^b Z_t + p_t^b I_t^b + \frac{\phi^b}{2}\left(\frac{I_t^b}{I_{t-1}^b} - 1\right)^2 p_t^b I_t^b \tag{A.48}$$

We can aggregate output and investment:

$$P_t Y_t = p_t^g Y_t^g + p_t^b Y_t^b \tag{A.49}$$

$$P_t I_t = p_t^g I_t^g + p_t^b I_t^b \tag{A.50}$$

Appendix B presents the full set of equilibrium conditions.

B Full set of equilibrium conditions

$$L_t = \left[(L_t^b)^{(1+\rho_L)} + (L_t^g)^{(1+\rho_L)} \right]^{\frac{1}{1+\rho_L}}, \tag{B.1}$$

$$M_{t,t+1} = \beta \frac{\left(C_{t+1} - \bar{\omega} \frac{L_{t+1}^{1+\xi}}{1+\xi} \right)^{-\eta}}{\left(C_t - \bar{\omega} \frac{L_t^{1+\xi}}{1+\xi} \right)^{-\eta}}, \tag{B.2}$$

$$\mathbb{E}_t(M_{t,t+1} R_t) = 1, \tag{B.3}$$

$$w_t^i = \bar{\omega} L_t^{\xi - \rho_L} (L_t^i)^{\rho_L}, \quad \text{for } i = \{g, b\} \tag{B.4}$$

$$\chi_t^b = \mathbb{E}_t \left[\Omega_{t+1} (R_{k,t+1}^b - (1+\tau^b) R_t \right], \tag{B.5}$$

$$\chi_t^g = \mathbb{E}_t \left[\Omega_{t+1} (R_{k,t+1}^g - (1+\tau^g) R_t \right], \tag{B.6}$$

$$\Omega_{t+1} = M_{t,t+1}(1 - \gamma + \gamma \varphi_{t+1}), \tag{B.7}$$

$$\nu_t = \mathbb{E}_t \left\{ \Omega_{t+1} R_t \right\}, \tag{B.8}$$

$$\frac{1}{\kappa_t^b} \chi_t^b = \frac{1}{\kappa_t^g} \chi_t^g, \tag{B.9}$$

$$\varphi_t = \frac{\kappa \nu_t}{\kappa - \chi_t^b}, \tag{B.10}$$

$$N_{t+1} = \gamma \left[\sum_{i=\{g,b\}} R_{k,t+1}^i Q_t^i S_t^i - R_t D_t \right] + \zeta \sum_{i=\{g,b\}} Q_t^i S_t^i, \tag{B.11}$$

$$D_t = (1+\tau^b) Q_t^b S_t^b + (1+\tau^g) Q_t^g S_t^g - N_t \tag{B.12}$$

$$\kappa_t^b Q_t^b S_t^b + \kappa_t^g Q_t^g S_t^g = \frac{\nu_t}{\kappa - \chi_t^b} N_t \tag{B.13}$$

$$Y_t^i = [1 - d(X_t)] A_t^i (K_{t-1}^i)^{\alpha^i} (L_t^i)^{1-\alpha^i}, \quad \text{for } i = \{g, b\} \tag{B.14}$$

$$C_t = \left[(\pi^b)^{\frac{1}{\rho_c}} (C_t^b)^{\frac{\rho_c - 1}{\rho_c}} + (1-\pi^b)^{\frac{1}{\rho_c}} (C_t^g)^{\frac{\rho_c - 1}{\rho_c}} \right]^{\frac{\rho_c}{\rho_c - 1}} \tag{B.15}$$

$$p_t^b = \left(\frac{\pi^b C_t}{C_t^b} \right)^{\frac{1}{\rho_c}} \tag{B.16}$$

$$p_t^g = \left(\frac{(1-\pi^b) C_t}{C_t^g} \right)^{\frac{1}{\rho_c}} \tag{B.17}$$

$$X_t = \delta_X X_{t-1} + e_t^b + e_t^{\text{row}}, \tag{B.18}$$

$$e_t^b = (1-\mu_t^b)Y_t^b, \tag{B.19}$$

$$Z_t^b = (1-\tau_t^z)\theta_1^b(\mu_t^b)^{\theta_2^b}Y_t^b, \tag{B.20}$$

$$w_t^b = (1-\alpha^b)\frac{Y_t^b}{L_t^b}[p_t^b - (1-\tau_t^z)p_t^b\theta_1^b(\mu_t^b)^{\theta_2^b} - \tau_t^e(1-\mu_t^b)] \tag{B.21}$$

$$\tau_t^e = (1-\tau_t^z)p_t^b\theta_1^b\theta_2^b(\mu_t^b)^{\theta_2^b-1} \tag{B.22}$$

$$R_{k,t}^b = \frac{\alpha^b\frac{Y_t^b}{K_{t-1}^b}[p_t^b - (1-\tau_t^z)p_t^b\theta_1^b(\mu_t^b)^{\theta_2^b} - \tau_t^e(1-\mu_t^b)] + (1-\delta^b)Q_t^b}{Q_{t-1}^b} \tag{B.23}$$

$$w_t^g = (1-\alpha^g)\,(1+\tau_t^g)\frac{Y_t^g}{L_t^g}p_t^g, \tag{B.24}$$

$$R_{k,t}^g = \frac{\alpha^g(1+\tau_t^g)\frac{Y_t^g}{K_{t-1}^g}p_t^g + (1-\delta^g)\,Q_t^g}{Q_{t-1}^g}. \tag{B.25}$$

$$Q_t^i = p_t^i\left[(1+\frac{\phi^i}{2}\left(\frac{I_t^i}{I_{t-1}^i}-1\right)^2+\phi^i\left(\frac{I_t^i}{I_{t-1}^i}-1\right)\frac{I_t^i}{I_{t-1}^i}\right]-\mathbb{E}_t\left\{M_{t,t+1}p_{t+1}^i\phi^i\left(\frac{I_t^i}{I_{t-1}^i}-1\right)\left(\frac{I_{t+1}^i}{I_t^i}\right)^2\right\}, \quad \text{for } i=\{g,b\} \tag{B.26}$$

$$K_t^i = (1-\delta^i)K_{t-1}^i + I_t^i, \quad \text{for } i=\{g,b\} \tag{B.27}$$

$$Y_t^b = C_t^b + I_t^b + Z_t^b + \frac{\phi^b}{2}\left(\frac{I_t^b}{I_{t-1}^b}-1\right)^2 I_t^b \tag{B.28}$$

$$Y_t^g = C_t^g + I_t^g + \frac{\phi^g}{2}\left(\frac{I_t^g}{I_{t-1}^g}-1\right)^2 I_t^g \tag{B.29}$$

$$Y_t = p_t^b Y_t^b + p_t^g Y_t^g \tag{B.30}$$

$$I_t = p_t^b I_t^b + p_t^g I_t^g \tag{B.31}$$

C Calibration

In the model, one period corresponds to one quarter. The model parameters fall into three categories: real business cycle (RBC) parameters, environmental parameters, and parameters related to financial frictions. Table 1 summarizes the parameter values. First, RBC parameters have a standard calibration. The discount factor β is calibrated to target an annualized risk-free rate of 1% in the steady state. The risk aversion parameter η is set at 2, the Frisch elasticity of labor hours $\frac{1}{\xi}$ is 1, and the intrasectoral CES of labor hours parameters, ρ_L is equal to 1, following the estimates of Horvath (2000) for the U.S. economy. The parameter weighting labor disutility is set such that the total hours worked in both sectors, $L_t = \frac{1}{3}$ in the initial steady state. The weight of brown consumption goods in the total consumption basket, π_t^b, is equal to one-third. Consistently with empirical estimates[9], the brown sector is slightly more capital-intensive than the green one, and we set $\alpha^b = 0.35$ and $\alpha^g = 0.33$. The rate of capital depreciation δ^i is the same between sectors, and calibrated at 0.025. Following Smets and Wouters (2003), the persistence and standard deviation of the aggregate TFP shock are $\rho_A^i = 0.95$, $\sigma_A^i = 0.007$. The investment adjustment cost parameter for both sectors (ϕ^i) is 10, in line with the parameter values also used in the environmental DSGE literature (e.g., Annicchiarico and Di Dio 2015).

Second, environmental parameters' calibration is based on the most version of the DICE model (Nordhaus 2018). We make some adjustments to ensure the consistency between DICE and our model. For instance, in our model, the damage is a quadratic function of the pollution stock. Following the environmental DSGE literature, we set: $d(X_t) = d_0 + d_1 X_t + d_2 X_t^2$. However, in the DICE model, the damage is a function of temperature, evolving according to a dynamic carbon stock. The adjustments we make are presented in Carattini et al. (2023a). Using the same methodology as in Gibson and Heutel (2023), we set the damage function parameter at $\widehat{d_0} = -0.026$, $\widehat{d_1} = 3.61e-5$, and $\widehat{d_2} = 1.44e-8$. We set the initial level of carbon stock at 1172 GtC[10] and rescale the damage function parameters accordingly. This implies that at the steady state, damages are 3.6% of output (i.e., $d(X_{ss,\text{model}}) = 0.0361$). Regarding the cost function, we rely on Nordhaus (2018)'s estimate and set θ_2^b to 2.6. For the calibration of θ_1^b, we use the same strategy as in Carattini et al. (2023a) to ensure consistency between our model and the most recent version of the DICE model. We obtain $\theta_1 = 0.0334$.[11] We calibrate the pollution parameter δ_X following Gibson and Heutel (2023). Finally, in line with

[9] See, for instance, Antweiler et al. (2001).

[10] It corresponds to the mean value of the carbon stock over the first 250 years of the simulation in the DICE optimal tax scenario.

[11] The reader will find more details on the strategy used in Carattini et al. (2023a)

the environmental DSGE literature, we assume that emissions from the rest of the world are constant ($e_t^{\text{row}} = e^{\text{row}}$) and calibrate them such that emissions from U.S. residents (e_t^b) represent one-sixth of global greenhouse gas emissions. The elasticity of substitution between brown and green consumption goods is set at 2, following the empirical estimation of Papageorgiou et al. (2017) for the substitution between green and brown inputs in the final good's production.

Third, the parameters related to financial frictions are set following Gertler and Karadi (2011). In the pre-investor shock steady state, the weight of the constraint on brown and green asset holding, κ_t^b and κ_t^g are set at 1. The bank survival rate γ is equal to 0.972. We calibrate the parameter associated with the fraction of divertible assets (κ) and the transfer parameter (ζ) to target a steady-state leverage ratio of 5 and annualized credit spreads of 90 basis points for both types of assets, consistent with empirical facts.

The model is simulated and solved using Dynare.

D Steady States

D.1 Carbon tax - Steady state

	No financial Frictions		Financial Frictions			
			No Macroprudential Policy		Macroprudential Policy	
	Before	After	Before	After	Before	After
Emission tax ($ per ton)	10.031	11.208	10.000	11.173	8.674	9.692
Tax brown assets (%)	-	-	0.000	0.000	0.470	0.470
Subsidy green assets (%)	-	-	0.000	0.000	0.470	0.470
Aggregate output	1.635	1.637	1.502	1.503	1.574	1.575
Climate damage (%)	3.735	3.660	3.609	3.541	3.485	3.426
Total emissions	0.474	0.450	0.434	0.412	0.394	0.375
Bank net worth	-	-	3.362	3.363	3.753	3.755
Brown credit spread (%)	0.000	0.000	0.250	0.250	0.723	0.723
Green credit spread (%)	0.000	0.000	0.250	0.250	-0.223	-0.223

Note: This table shows the steady state values of selected variables in the economies with and without financial frictions following an increase in the carbon tax and under different policy scenarios. Tax rates on banks' assets, credit spreads, and the subsidy rate are in percentages. Climate damages are in percent of output. All other variables are in arbitrary model units. "Before" refers to the initial value of the variable, prior to the increase in the carbon tax while "After" is the value of the variable following the increase.

In columns 1 and 2, we simulate a model with no financial frictions, where households directly lend to good-producing firms. The subsequent columns present the steady state values under financial frictions, as described in Section 2. In columns 3 and 4, there is no macroprudential policy: $\tau^b = \tau^g = 0$. In columns 5 and 6, there is an ex-ante macroprudential policy: before the introduction of the subsidy in quarter 5, banks are subject to taxes on brown assets and subsidies on green assets. Macroprudential taxes, credit spreads, and climate damages are expressed in percentages.

In the model with financial frictions, the economy starts with lower aggregate output (comparing column 1 to columns 3 and 5). This is because banks are constrained in the loan amount they can issue. When a tax-and-subsidy scheme is present (two last columns), the aggregate output is higher in the pre-shock steady state (comparing column 3 and 5) because this policy reduces the suboptimal allocation of resources generated by the presence of financial frictions.

Comparing the columns "Before" and "After" in each of these three scenarios reveals that an increase in carbon pricing generates a drop in economic activity and banks' net worth. The environmental benefits of higher carbon pricing are visible through a decrease in total emissions under the three scenarios, enabling lower climate damage.

D.2 Abatement subsidy - Steady state

	No financial Frictions		Financial Frictions			
			No Macroprudential Policy		Macroprudential Policy	
	Before	After	Before	After	Before	After
Subsidies abatement (%)	0	10.993	0	10.993	0	10.993
Tax brown assets (%)	-	-	0	0	0.47	0.47
Subsidies green assets (%)	-	-	0	0	0.47	0.47
Aggregate output	1.635	1.639	1.502	1.505	1.574	1.577
Climate damage (%)	3.735	3.66	3.609	3.541	3.485	3.426
Total emissions	0.474	0.45	0.434	0.412	0.394	0.375
Bank net worth	-	-	3.362	3.371	3.753	3.762
Brown credit spread (%)	0	0	0.25	0.25	0.723	0.723
Green credit spread (%)	0	0	0.25	0.25	-0.223	-0.223
Abatement	0.412	0.443	0.411	0.443	0.401	0.432
Share green assets (%)	58.228	58.202	58.33	58.305	70	69.98

Note: This table shows the steady state values of selected variables in the economies with and without financial frictions following the introduction of an abatement subsidy and under different policy scenarios. Tax rates on banks' assets, credit spreads, and the subsidy rate are in percentages. Climate damages are in percent of output. All other variables are in arbitrary model units. "Before" refers to the initial value of the variable, prior to the introduction of the subsidy while "After" is the value of the variable following the introduction.

In each scenario, comparing the columns "Before" and "After", a 11% subsidy on emission abatement generates an increase in abatement, leading to a 5% decrease in total emissions, attenuating climate damage. This subsidy also slightly increases aggregate output. Over the long run, this policy has environmental benefits without affecting economic activity.

D.3 Green producer subsidy - Steady state

	No financial Frictions		Financial Frictions			
			No Macroprudential Policy		Macroprudential Policy	
	Before	After	Before	After	Before	After
Subsidy green producers (%)	0,000	5.000	0.000	5.000	0.000	5.000
Tax brown assets (%)	-	-	0.000	0.000	0.470	0.470
Subsidy green assets (%)	-	-	0.000	0.000	0.470	0.470
Aggregate output	1.635	1.731	1.502	1.590	1.574	1.672
Climate damage (%)	3.735	3.767	3.609	3.639	3.485	3.511
Total emissions	0.474	0.484	0.434	0.443	0.394	0.402
Bank net worth	-	-	3.362	3.665	3.753	4.141
Brown credit spread (%)	0.000	0.000	0.250	0.250	0.723	0.723
Green credit spread (%)	0.000	0.000	0.250	0.250	-0.223	-0.223
Brown production	0.805	0.817	0.737	0.748	0.659	0.668
Green production	0.868	0.946	0.799	0.871	0.926	1.010
Brown capital stock	10.086	10.234	8.463	8.592	6.535	6.630
Green capital stock	10.415	11.917	8.791	10.056	12.088	13.845

Note: This table shows the steady state values of selected variables in the economies with and without financial frictions following the introduction of subsidies for green producers and under different policy scenarios. Tax rates on banks' assets, credit spreads, and the subsidy rate are in percentages. Climate damages are in percent of output. All other variables are in arbitrary model units. "Before" refers to the initial value of the variable, prior to the introduction of the subsidy while "After" is the value of the variable following the introduction.

A 5% subsidy increasing green marginal revenue favors the production in this sector, which increases in the three scenarios we simulate. This expansion spills over the brown sector, whose production also increases. It leads to an increase in aggregate output and emissions. After the introduction of the subsidy, the net worth of the banking sector increases as well. This increase in net worth triggers higher loan supply, favoring investment and thus, the capital stock in both sectors.

D.4 Consumers' preference shock - Steady state

	No financial Frictions		Financial Frictions			
			No Macroprudential Policy		Macroprudential Policy	
	Before	After	Before	After	Before	After
Weight green consumption good	0.668	0.697	0.668	0.697	0.668	0.697
Share green consumption good (%)	0.536	0.551	0.537	0.552	0.566	0.58
Tax brown assets (%)	-	-	0	0	0.47	0.47
Subsidy green assets (%)	-	-	0	0	0.47	0.47
Aggregate output	1.635	1.606	1.502	1.475	1.574	1.556
Climate damage (%)	3.735	3.66	3.609	3.541	3.485	3.426
Total emissions	0.474	0.45	0.434	0.412	0.394	0.375
Bank net worth	-	-	3.362	3.298	3.753	3.73
Brown credit spread (%)	0	0	0.25	0.25	0.723	0.723
Green credit spread (%)	0	0	0.25	0.25	-0.223	-0.223
Share green assets (%)	58.228	60.374	58.33	60.474	70	71.833

Note: This table shows the steady state values of selected variables in the economies with and without financial frictions following a consumer's preference shock and under different policy scenarios. Tax rates on banks' assets, credit spreads, and the shares of green consumption goods and green assets are in percentages. Climate damages are in percent of output. All other variables are in arbitrary model units. "Before" refers to the initial value of the variable, prior to the preference shock while "After" is the value of the variable following the preference shock.

Under these three scenarios, a preference shock increasing the weight of the green good in the consumption basket naturally leads to an increase in the steady-state share of green consumption good, defined as $\frac{\bar{C^g}}{\bar{C}}$. This preference shock constitutes a source of transition risk: following this shock, aggregate output and banks' net worth decrease. As the demand for the brown consumption goods decreases, production in the brown sector decreases, and we can observe a resulting drop in emissions and climate damages following the preference shock.

D.5 Investors' preference shock - Steady state

	No Macroprudential Policy		Macroprudential Policy	
	Before	After	Before	After
Weight brown constraint	1.000	1.883	1.000	1.883
Weigh green constraint	1.000	0.441	1.000	0.441
Tax brown assets (%)	0.000	0.000	0.470	0.470
Subsidies green assets (%)	0.000	0.000	0.470	0.470
Share green assets (%)	58.330	62.854	70.000	73.763
Aggregate output	1.502	1.502	1.574	1.599
Climate damage (%)	3.609	3.541	3.485	3.439
Total emissions	0.434	0.412	0.394	0.379
Bank net worth	3.362	3.326	3.753	3.538
Brown credit spread (%)	0.250	0.469	0.723	0.925
Green credit spread (%)	0.250	0.110	-0.223	-0.367

Note: This table shows the steady state values of selected variables in the economies with and without macroprudential policy following an investor's preference shock and under different policy scenarios. Tax rates on banks' assets, credit spreads, and the shares of green consumption goods and green assets are in percentages. Climate damages are in percent of output. All other variables are in arbitrary model units. "Before" refers to the initial value of the variable, prior to the preference shock while "After" is the value of the variable following the preference shock.

The compositional shock in the weights on brown and green asset constraints triggers an increase in the share of green assets in the banking sector's portfolio. Over the long run, both in the presence and the absence of macroprudential policy, this shock triggers a slight decrease in banks' net worth that does not generate transition risk as the output is unchanged. In the presence of macroprudential policy, the pre-shock exposure to green assets is higher, therefore, the effects of these shocks are amplified (for example, the decrease in the banking sector's net worth is higher in the presence of macroprudential policy).

E Sensitivity

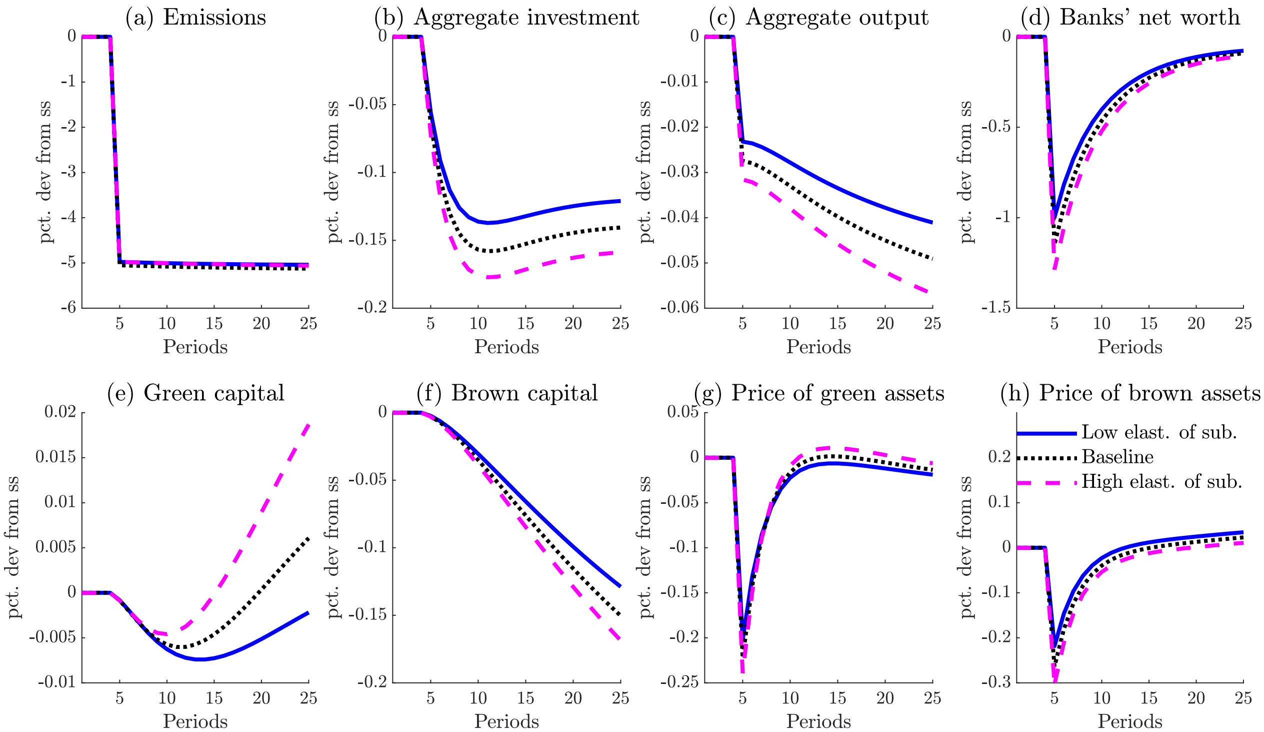
We explore here the sensitivity of our results in the model with financial frictions and no ex-ante macroprudential policy to parameter values. The elasticity of substitution between the "green" and the "brown" consumption good, ρ_c, influences sectoral reallocations when a shock hits one sector. In the baseline calibration, we set $\rho_c = 2$. The subsequent Figures (E.1 - E.5) report the dynamics of the transition under this baseline case (dotted line) along with the transitions when the sensitivity is lower (solid blue line, $\rho_c = 1.5$) and when it is higher (solid pink line, $\rho_c = 3$). In all the scenarios we consider and for all the values of ρ_c we consider, we calibrate the shock such that it triggers a 5% decrease in emissions after the transition[12].

First, for all the shocks we consider, the qualitative transition results obtained with the baseline calibration hold with alternative reasonable parameter values. However, the degree of substitutability between both goods affects the *magnitude* of the response of our variables following a shock.

As an illustration, we consider the increase in carbon pricing reported in Figure E.1. When the degree of substitutability is lower (blue lines), households' ability to divert from brown consumption goods is reduced. As a result, brown production reduces more, as evidenced by the lower decrease in brown capital (Panel (f)). Consequently, the price of brown assets experiences a lower asset stranding (Panel (h)), mitigating the drop in banks' net worth (Panel (d)). Overall, with lower elasticity of substitution, aggregate investment and output fall by less than in the baseline case (Panels (b) and (c)). In opposition, when the elasticity of substitution is higher, the production in the green sector increases more and the production in the dirty sector decreases more. In this case, banks experience larger losses (Panel (d)), deepening the recession (Panel (c)).

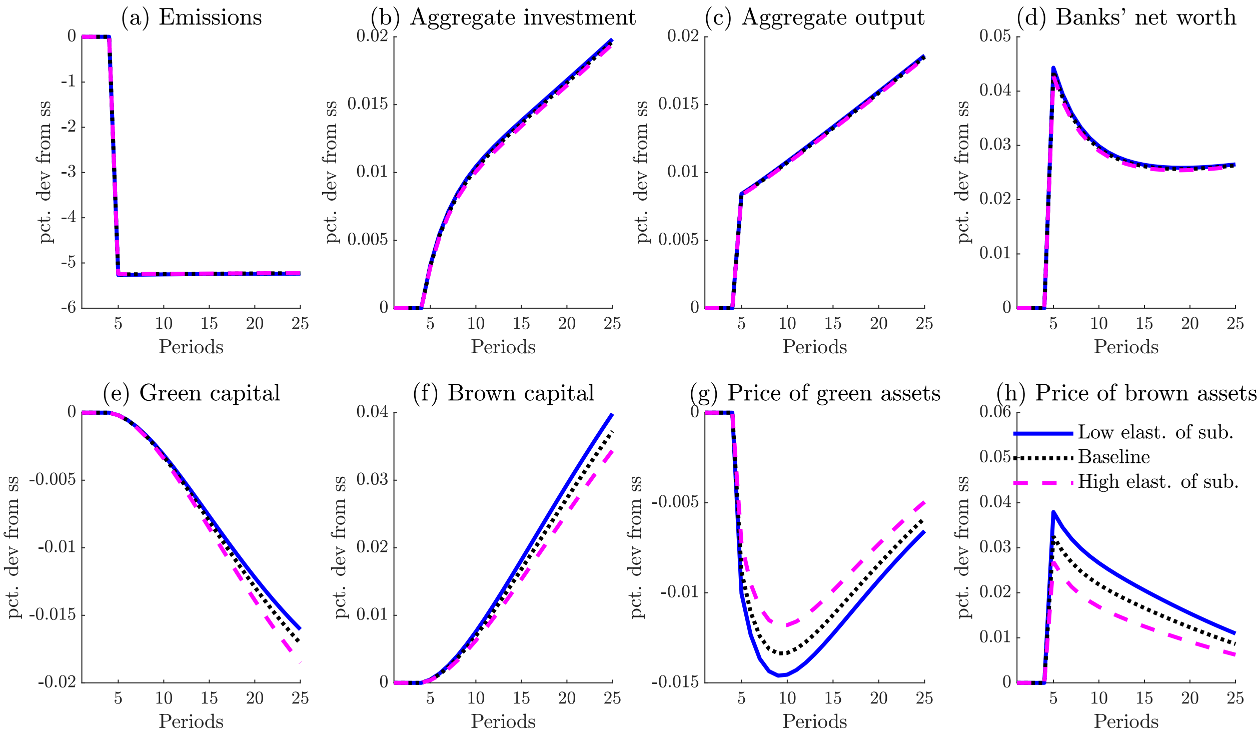
[12]Except for the green subsidies. In this case, we calibrate a 5% subsidy.

Figure E.1: Sensitivity - Carbon pricing



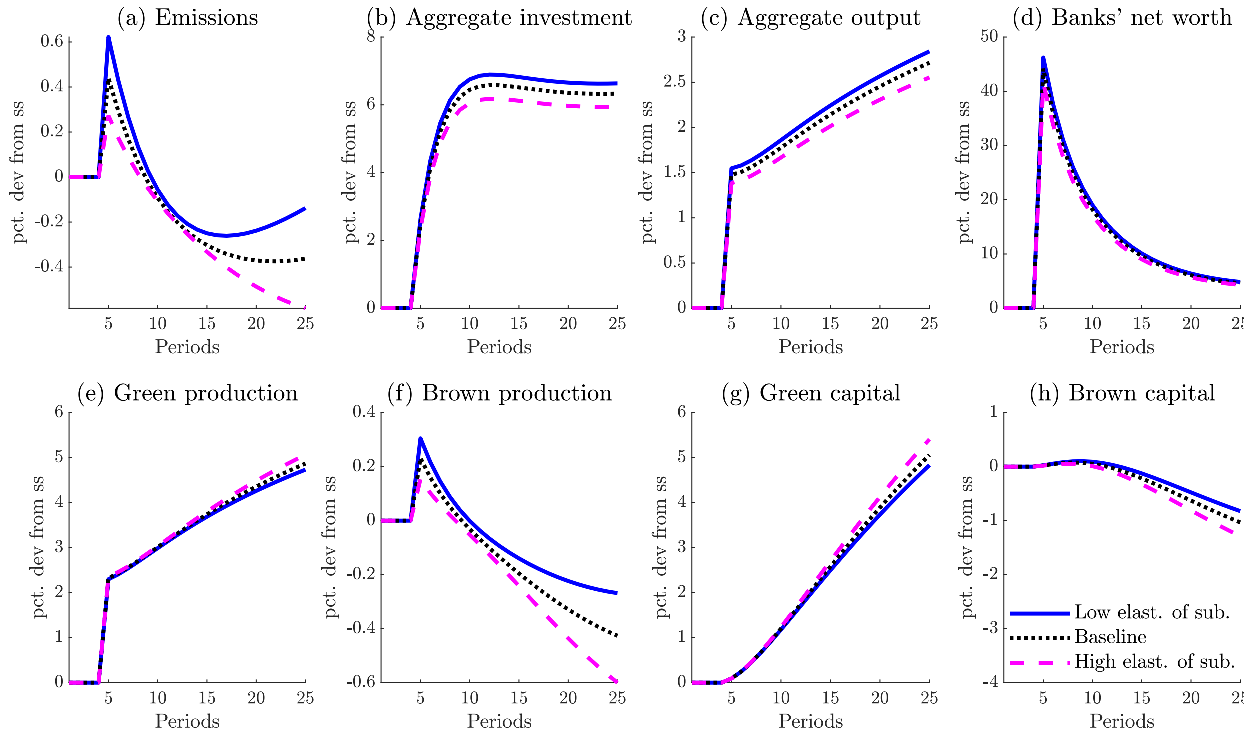
Note: This figure plots the transition dynamics to the increase in carbon pricing under three scenarios: (i) Baseline case (dotted lines); (ii) lower elasticity of substitution between consumption goods (blue line); (iii) higher elasticity of substitution (pink line). Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

Figure E.2: Sensitivity - Abatement subsidies



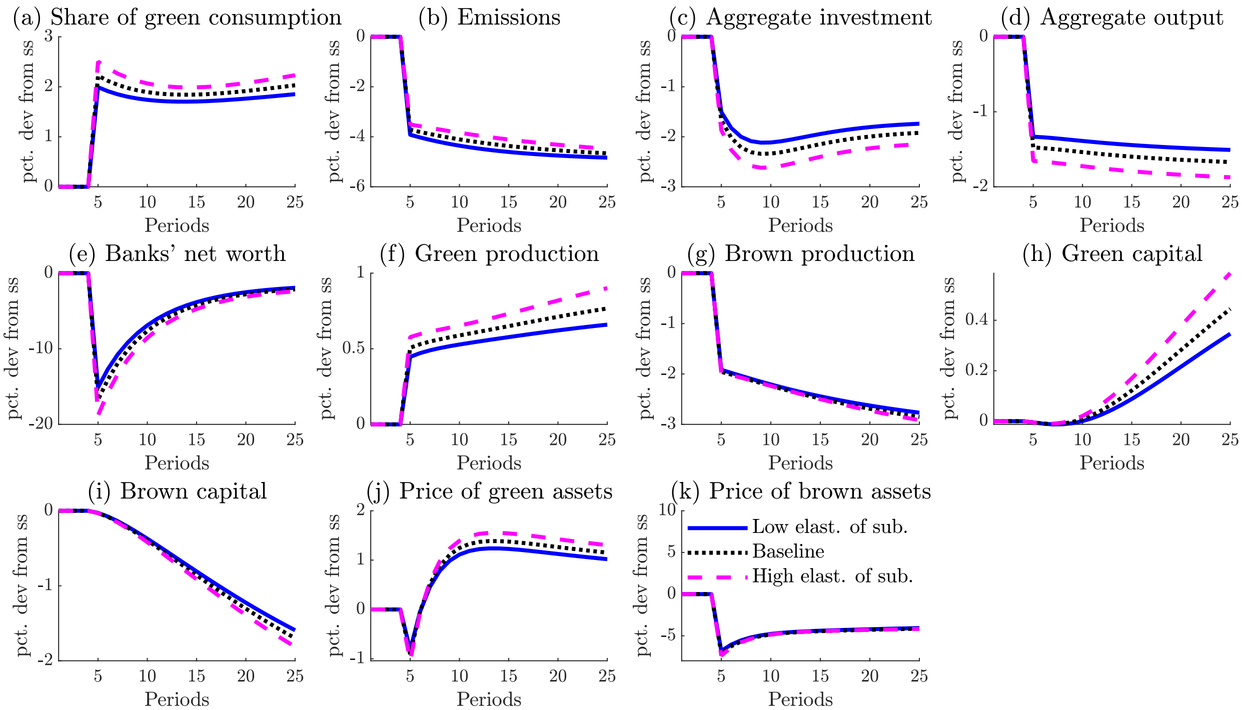
Note: This figure plots the transition dynamics to the introduction of abatement subsidies under three scenarios: (i) Baseline case (dotted lines); (ii) lower elasticity of substitution between consumption goods (blue line); (iii) higher elasticity of substitution (pink line). Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

Figure E.3: Sensitivity - Green producers subsidies



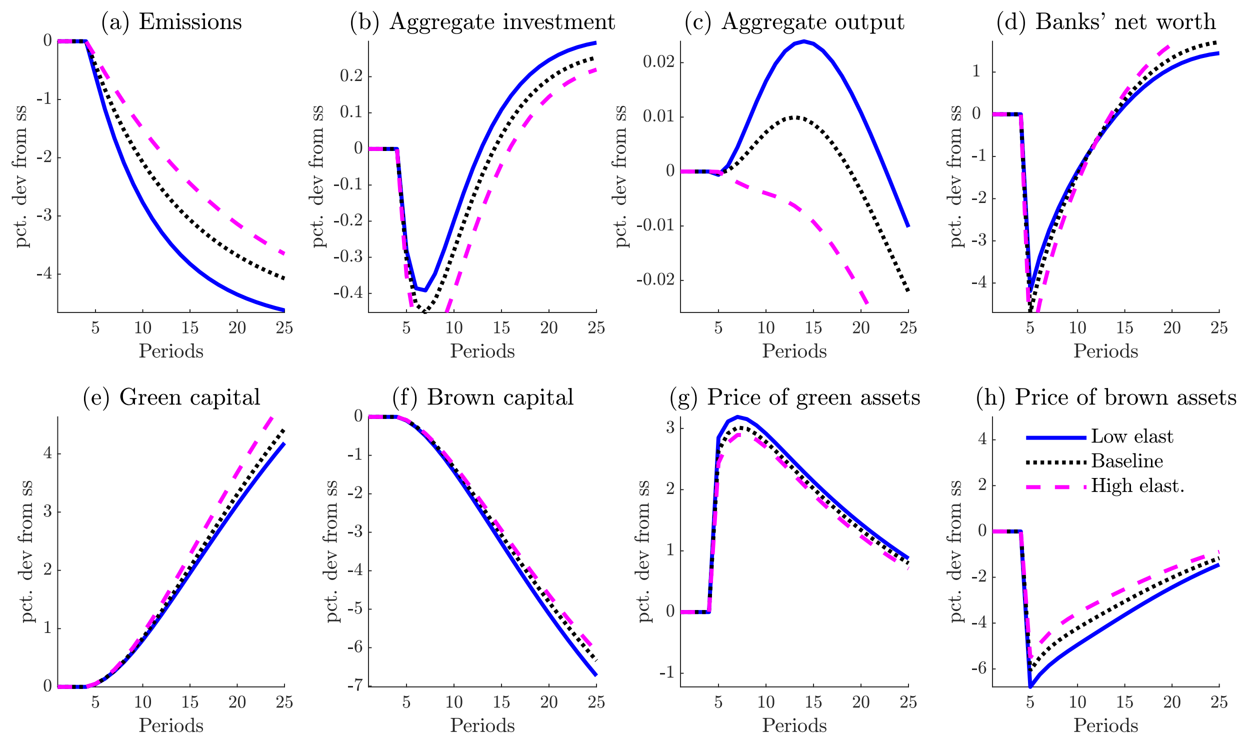
Note: This figure plots the transition dynamics to the introduction of subsidies for green producers under three scenarios: (i) Baseline case (dotted lines); (ii) lower elasticity of substitution between consumption goods (blue line); (iii) higher elasticity of substitution (pink line). Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

Figure E.4: Sensitivity - Consumers' preference shock



Note: This figure plots the transition dynamics to a consumer preference shock under three scenarios: (i) Baseline case (dotted lines); (ii) lower elasticity of substitution between consumption goods (blue line); (iii) higher elasticity of substitution (pink line). Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

Figure E.5: Sensitivity - Investors' preference shock



Note: This figure plots the transition dynamics to an investor preference shock under three scenarios: (i) Baseline case (dotted lines); (ii) lower elasticity of substitution between consumption goods (blue line); (iii) higher elasticity of substitution (pink line). Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

F Simultaneous shocks: Other cases

We present here the other possible combinations of shocks occurring simultaneously.

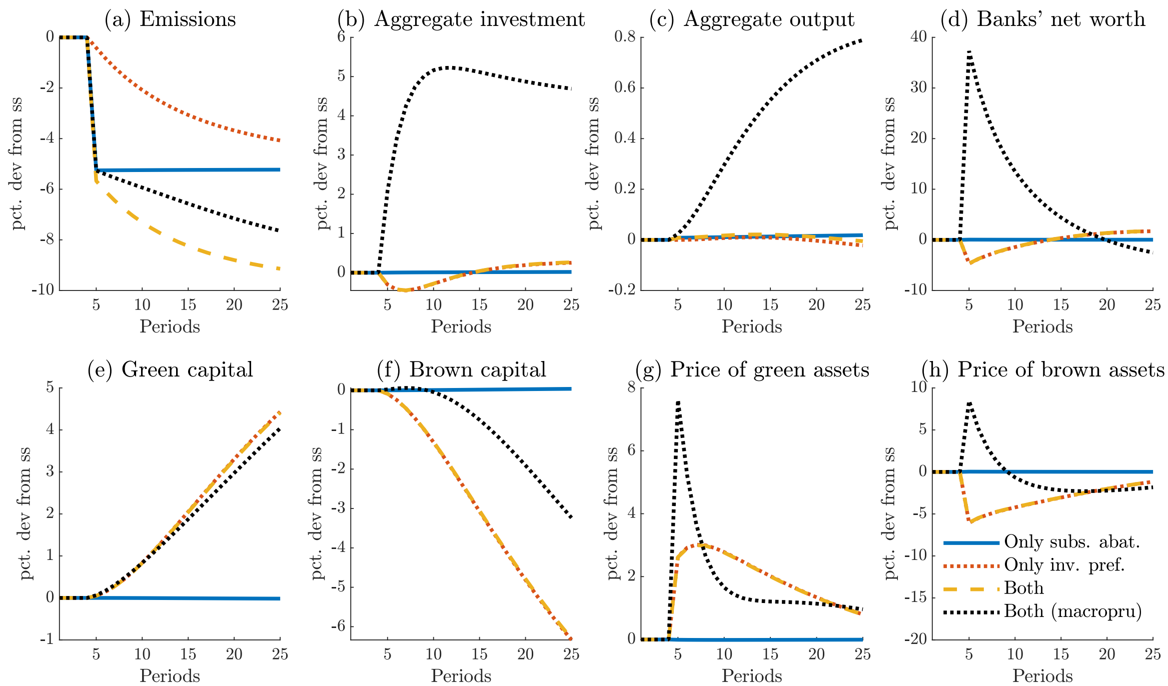
F.1 Abatement subsidies and investor preferences shocks

We assume here that a subsidy on abatement is introduced simultaneously with an investor's shock favoring green asset holdings. We report in Figure F.1 the dynamics of the model. Solid lines represent the dynamics without macroprudential policy while dotted lines report the trajectory of our variables in the presence of macroprudential policy.

As we previously emphasized, the abatement subsidy alone has only a limited effect. Therefore, when both shocks co-occur, the dynamics of the economy is driven by the investor preference shock.

We now turn to the effect of macroprudential policy when both shocks co-occur. As we exposed in Section 3.2.2, the green macroprudential policy magnifies the effects of the investor preference shock. In the scenario considered here, when it co-occurs with the introduction of abatement subsidies, this shock drives the response of the economy. Therefore, when both shocks simultaneously hit the economy, the presence of macroprudential policy also amplifies the expansionary effects of these two sources of stimulus. The increase in green asset prices is more important (Panel (g)) and, therefore, banks experience an increase in net worth (Panel (d)). It leads to a higher increase in aggregate investment and output (Panels (b) and (c)).

Figure F.1: Co-occurence of the introduction of an abatement cost subsidy and investors' preference shock



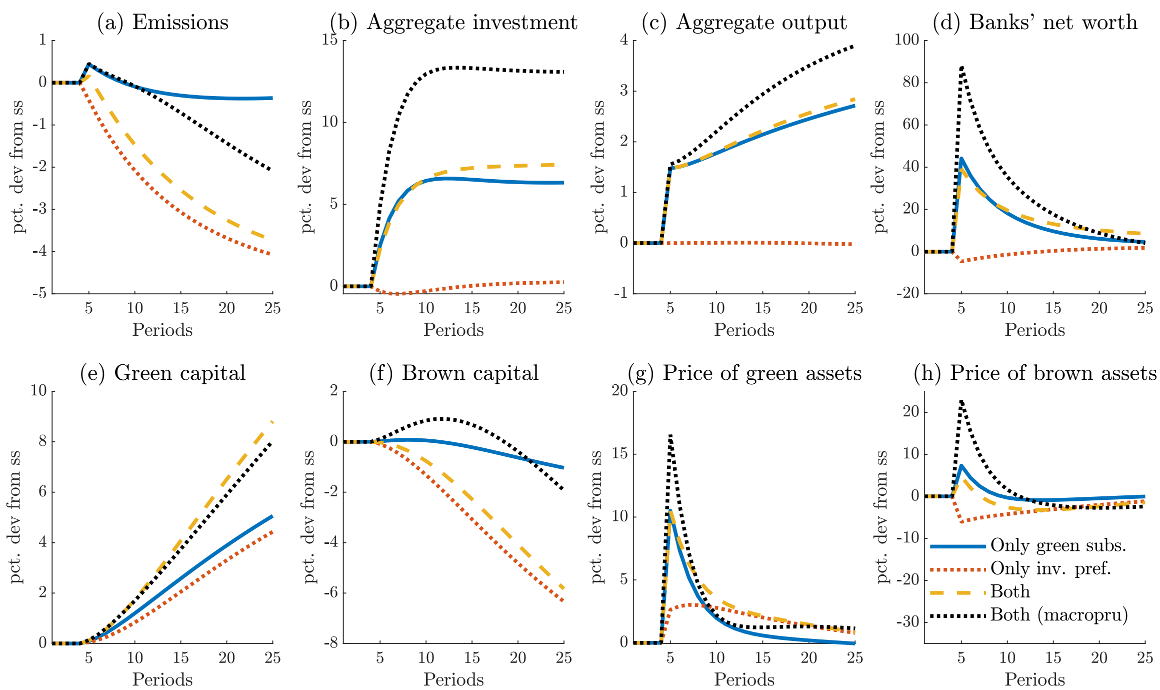
Note: This figure plots the transition dynamics to the combination between the introduction of an abatement cost subsidy and a preference shock among investors under four scenarios: (i) only the abatement subsidy shock occurs without macroprudential policy (solid lines); (ii) only the investor preference shock occurs without macroprudential policy (red dotted lines); (iii) both shocks co-occur without macroprudential policy (yellow dashed lines) and (iv) both shocks co-occur with macroprudential policy (black dotted lines). Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

F.2 Green producer subsidies and investor preferences shocks

We simulate here two exogenous sources of stimulus hitting the economy simultaneously: the introduction of subsidies on green producers' marginal revenues and investor preference shocks favoring green asset holdings. Figure F.2 reports the dynamics when, in quarter 5, both shocks co-occur. When both shocks co-occur without ex-ante macroprudential policy, the solid lines show that the macroeconomic and financial variables' responses are primarily driven by the policy shock (see, notably, aggregate investment, output, and banks' net worth in Panels (b) to (d)).

We now turn to investigating the effects of macroprudential policy in the presence of these two sources of stimulus (dotted lines). When these shocks occur in isolation, Figures 3 and 5 reported that the green macroprudential policy, by diverting the banking sector's exposure to the collapsing brown sector, amplifies the expansionary effects of the shocks. Therefore, it has comparable effects when both shocks occur simultaneously: aggregate investment, output, and banks' net worth increase more than when there is no such policy in place (Panels (b) to (d)).

Figure F.2: Co-occurence of the introduction of a green producers' subsidy and investors' preference shock



Note: This figure plots the transition dynamics to the combination between the introduction of a subsidy for green producers and a preference shock among investors under four scenarios: (i) only the green subsidy shock occurs without macroprudential policy (solid lines); (ii) only the investor preference shock occurs without macroprudential policy (red dotted lines); (iii) both shocks co-occur without macroprudential policy (yellow dashed lines) and (iv) both shocks co-occur with macroprudential policy (black dotted lines). Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

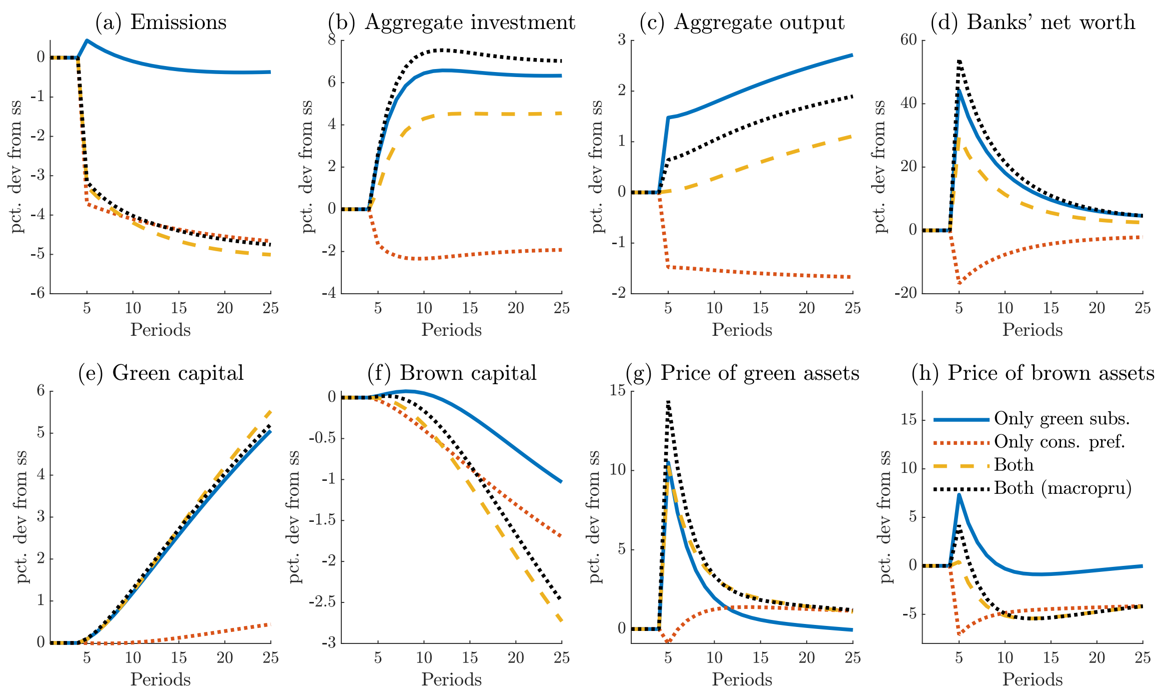
F.3 Consumer preferences and green producer subsidy shocks

We now examine how the economy reacts when it faces a recessionary and an expansionary shock simultaneously. We simulate here the co-occurrence of a consumer preference shock and the introduction of subsidies for green producers. Figure F.3 reports the dynamics when a macroprudential policy exists prior to the occurrence of these shocks (dotted lines) and banks were not subject to this policy (solid lines).

Under our calibration, the expansionary effects triggered by the stimulus dominate the recessionary effect generated by the consumer preference shock; when both shocks co-occur, aggregate output, and aggregate investment (Panels (b) and (c)) increase. Besides, as both shocks, taken in isolation, favor the green sector, the increase in green production and the decrease in brown production are amplified, as evidenced by the demand for sector-specific capital (Panels (e) and (f)).

We now examine the effect of macroprudential policy in the simultaneous presence of both shocks, focusing on dotted lines. The macroprudential policy shifts banks away from brown assets. Therefore, when two shocks triggering a collapse in the brown sector occur simultaneously, the increase in bank net worth is magnified (Panel (d)). This surge ensures a higher expansion in credit, generating a higher increase in aggregate investment and output (Panels (b) and (c)).

Figure F.3: Co-occurence of the introduction of a green producers' subsidy and a consumer preference shock



Note: This figure plots the transition dynamics to the combination between the introduction of a green producers' subsidies and a consumer's preference shock under four scenarios: (i) only the green subsidy shock occurs without macroprudential policy (solid lines); (ii) only the consumer preference shock occurs without macroprudential policy (red dotted lines); (iii) both shocks co-occur without macroprudential policy (yellow dashed lines) and (iv) both shocks co-occur with macroprudential policy (black dotted lines). Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

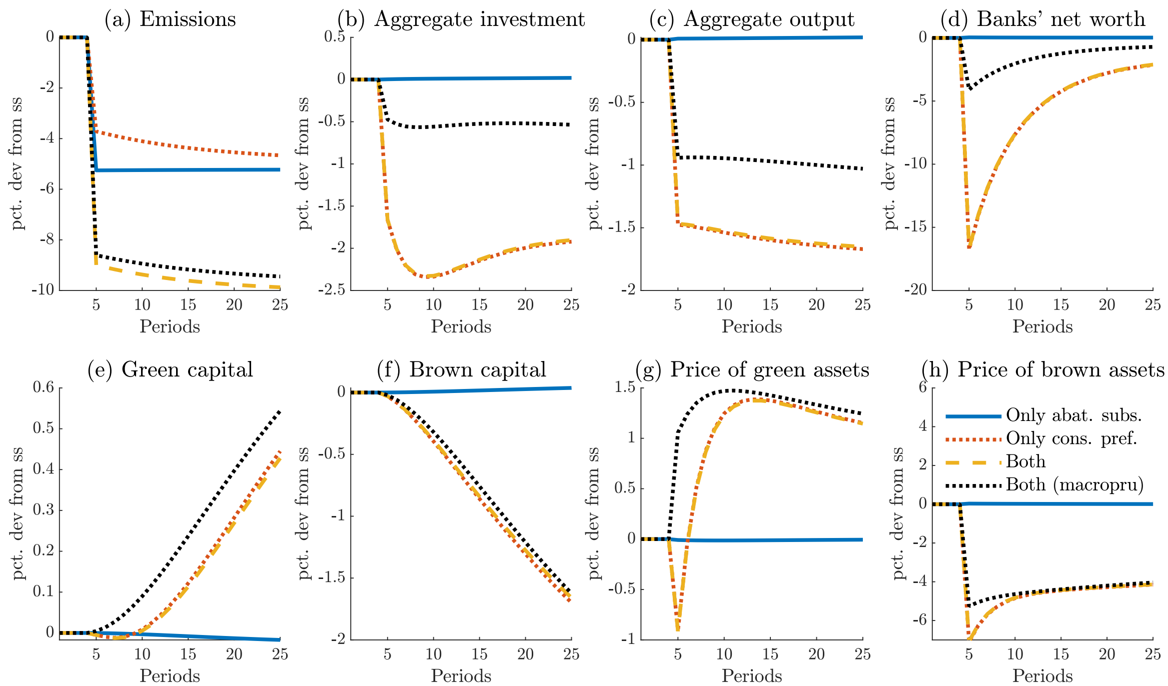
F.4 Consumer preferences and abatement subsidy shocks

We investigate here whether the introduction of the abatement cost subsidy can attenuate the transition risk constituted by consumers' preference shocks. We report in Figure F.4 the response of key variables when the two shocks co-occur without ex-ante macroprudential policy (solid lines) and when the tax and subsidies exist prior to the shocks (dotted lines).

The effects of the abatement subsidies on macroeconomic and financial variables are low, and the preference shock dominates. When both shocks hit the economy, aggregate investment, output, and bank net worth decrease (Panels (b), (c) and (d)). Therefore, the abatement subsidies are not sufficient to prevent the realization of transition risk arising because of the preference shock. Panel (a) shows that emissions decrease more when both shocks co-occur, for two reasons. First, because the preference shock decreases the demand for the brown consumption good, its production decreases, as evidenced by the collapse in brown capital (Panel (f)), leading to a decrease in aggregate emissions. Second, emissions further decrease because the abatement cost is partially subsidized by the government, increasing abatement and ensuring a higher decrease in aggregate emissions than when only the preference shock occurs.

We now assess the effectiveness of macroprudential policies in mitigating this source of transition risk. By lowering the banking sector's exposure to brown assets, macroprudential policy mitigates the recessionary effects triggered by the collapse of the brown sector induced by consumers' preference shock. Consequently, the decrease in banks' net worth is lower in this scenario (Panel (d)), and the credit crunch is attenuated. It results in a lower contraction in economic activity (Panels (b) and (c)).

Figure F.4: Co-occurence of the introduction of an abatement cost subsidy and a consumer preference shock



Note: This figure plots the transition dynamics to the combination between the introduction of an abatement cost subsidy and a consumer's preference shock under four scenarios: (i) only the abatement shock occurs without macroprudential policy (solid lines); (ii) only the consumer preference shock occurs without macroprudential policy (red dotted lines); (iii) both shocks co-occur without macroprudential policy (yellow dashed lines) and (iv) both shocks co-occur with macroprudential policy (black dotted lines). Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

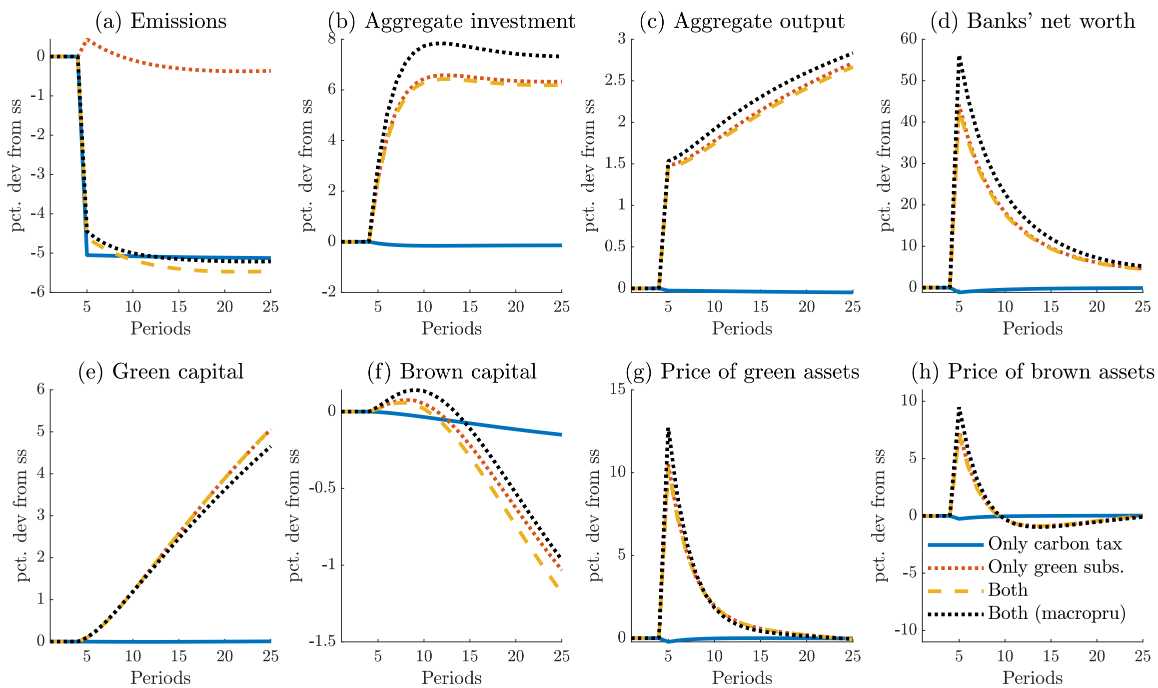
F.5 Carbon tax and green producer subsidy shocks

We examine here the reaction of the economy when the government simultaneously implements a subsidy to green producers and increases carbon pricing. Figure F.5 reports the dynamics of the model when both shocks hit the economy simultaneously. Solid lines report the transition following the shock without macroprudential policy. In this case, the expansionary effects of the subsidy's introduction dominated the recessionary effects of the carbon tax shock and, overall, when both shocks occur, aggregate investment, aggregate output, and banks' net worth increase (Panels (b), (c) and (d), respectively). Besides, because of the increase in the carbon tax, aggregate emissions decrease (Panel (a)) while the brown sector collapses in response of both shocks (Panel (f)).

Dotted lines show that, when both shocks occur, the presence of ex-ante macroprudential policy triggers a higher increase in banks' net worth than without macroprudential policy (Panel (d)). This is because, through the tax-and-subsidy scheme, banks divert from brown assets, and their exposure to the collapse of this sector is therefore limited.

Overall, in terms of policy recommendations, the introduction of a subsidy on green producers' marginal cost triggers an economic expansion, both when it is used in isolation but also in combination with other shocks, allowing to prevent the recessionary effects of a shock generating transition risk. Moreover, when the policy package is constituted by this subsidy and a carbon tax, policymakers can achieve both an increase in economic activity and a reduction in aggregate emissions, favoring the transition to a low-carbon economy with no economic or financial costs.

Figure F.5: Co-occurence of the introduction of a green producers' subsidy and a carbon tax shock



Note: This figure plots the transition dynamics to the combination between the introduction of green producers' subsidy and a carbon tax shock under four scenarios: (i) only the carbon tax shock occurs without macroprudential policy (solid lines); (ii) only the green subsidy shock occurs without macroprudential policy (red dotted lines); (iii) both shocks co-occur without macroprudential policy (yellow dashed lines) and (iv) both shocks co-occur with macroprudential policy (black dotted lines). Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

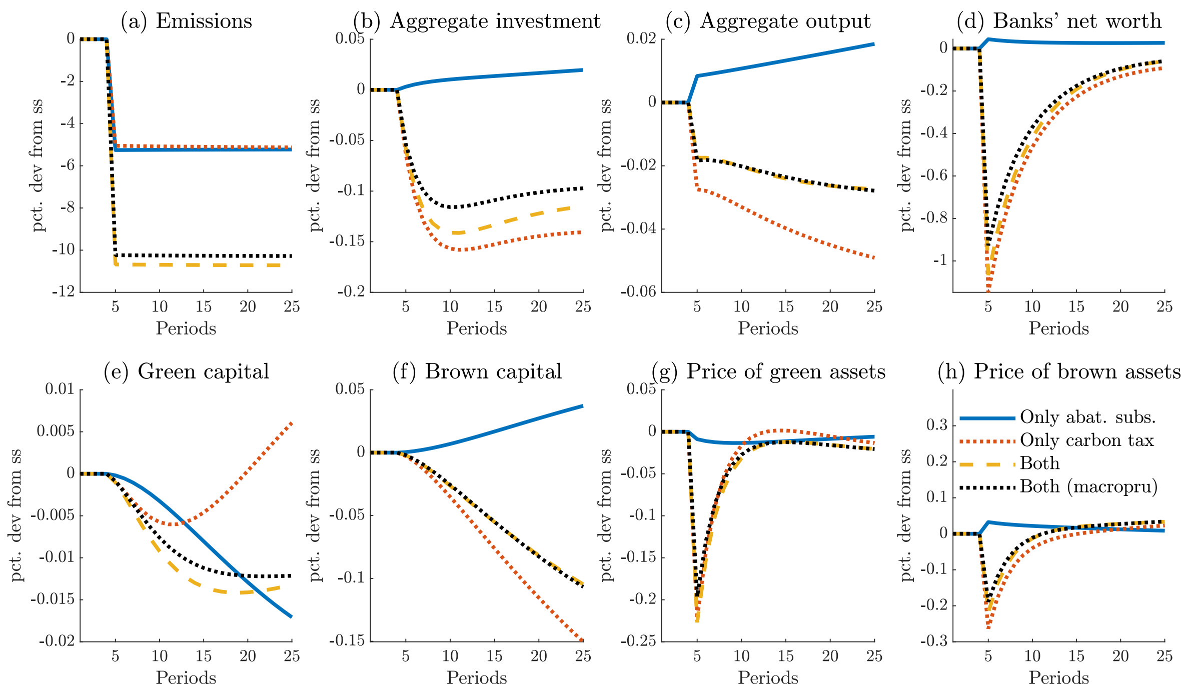
F.6 Carbon tax and abatement subsidy shocks

We examine here the effect of risk compounding when the economy simultaneously faces an increase in carbon price and the introduction of a subsidy on abatement cost. We plot in Figure F.6 the response of key variables when the government implements both policies (dashed lines) in quarter 5. Solid lines report the results without ex-ante macroprudential policy while dotted lines correspond to the case where macroprudential policy is present. All variables are expressed in percentage deviation from their initial steady state under the three scenarios.

As we previously noted, the expansionary effects of the abatement subsidy are limited. Therefore, when the government also increases the carbon tax, the response of the economy is driven by this source of transition risk. The decrease in bank net worth, output, and investment is of the same magnitude as when the increase in carbon pricing occurs in isolation (Panels (d), (c), and (b)). Emissions decrease by 10%, as abatement is less costly.

We examine the effect of macroprudential policy when both shocks co-occur. The dotted lines show that macroprudential policy slightly mitigates the negative effects of this risk compounding on banks' net worth and economic activity through the mechanisms presented in Sections 3.1.1 and 3.1.2.

Figure F.6: Co-occurence of the introduction of an abatement cost subsidy and a carbon tax shock



Note: This figure plots the transition dynamics to the combination between the introduction of an abatement cost subsidy and a carbon tax shock under four scenarios: (i) only the abatement subsidy shock occurs without macroprudential policy (solid lines); (ii) only the carbon tax shock occurs without macroprudential policy (red dotted lines); (iii) both shocks co-occur without macroprudential policy (yellow dashed lines) and (iv) both shocks co-occur with macroprudential policy (black dotted lines). Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

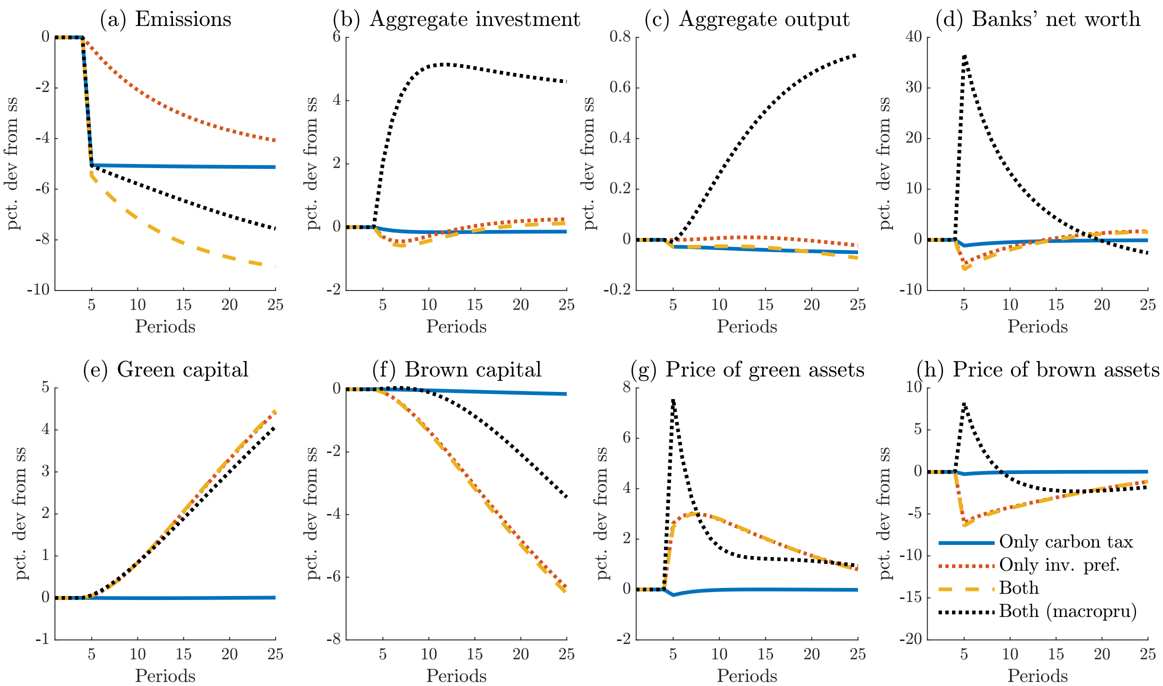
F.7 Carbon tax and investor preferences shock

How would an economy react if the government implements a carbon tax when investors shift the composition of their portfolio to favor green asset holdings? To answer this question, we simulate a source of risk compounding when both shocks occur simultaneously and report in Figure F.7 the dynamics of our model when both shocks co-occur without and with macroprudential policy (solid and dashed lines, respectively).

Compared to the recessionary effects of the carbon tax shock, the expansionary effects of the investor preference shock are smaller. Therefore, when both shocks co-occur, aggregate investment, output, and banks' net worth decrease without macroprudential policy (Panels (b) to (d)). Therefore, this source of risk compounding materializes in transition risk, and the stranding in brown asset prices is even more pronounced (Panel (h)).

The presence of macroprudential policy is effective in mitigating the transition risk resulting from the co-occurrence of both shocks: brown asset now experience valuations (Panel (h)) and the increase in the price of green assets is magnified (Panel (g)), generating an increase in banks' net worth (Panel (d)). It results in an increase in aggregate investment and aggregate output (Panels (b) and (c)).

Figure F.7: Co-occurence of the investors' preference and a carbon tax shocks



Note: This figure plots the transition dynamics to the combination between the preference shock among consumers and a carbon tax shock under four scenarios: (i) only the carbon tax shock occurs without macroprudential policy (solid lines); (ii) only the investor preference shock occurs without macroprudential policy (red dotted lines); (iii) both shocks co-occur without macroprudential policy (yellow dashed lines) and (iv) both shocks co-occur with macroprudential policy (black dotted lines). Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

G Transition risk when a recession hits: Other cases

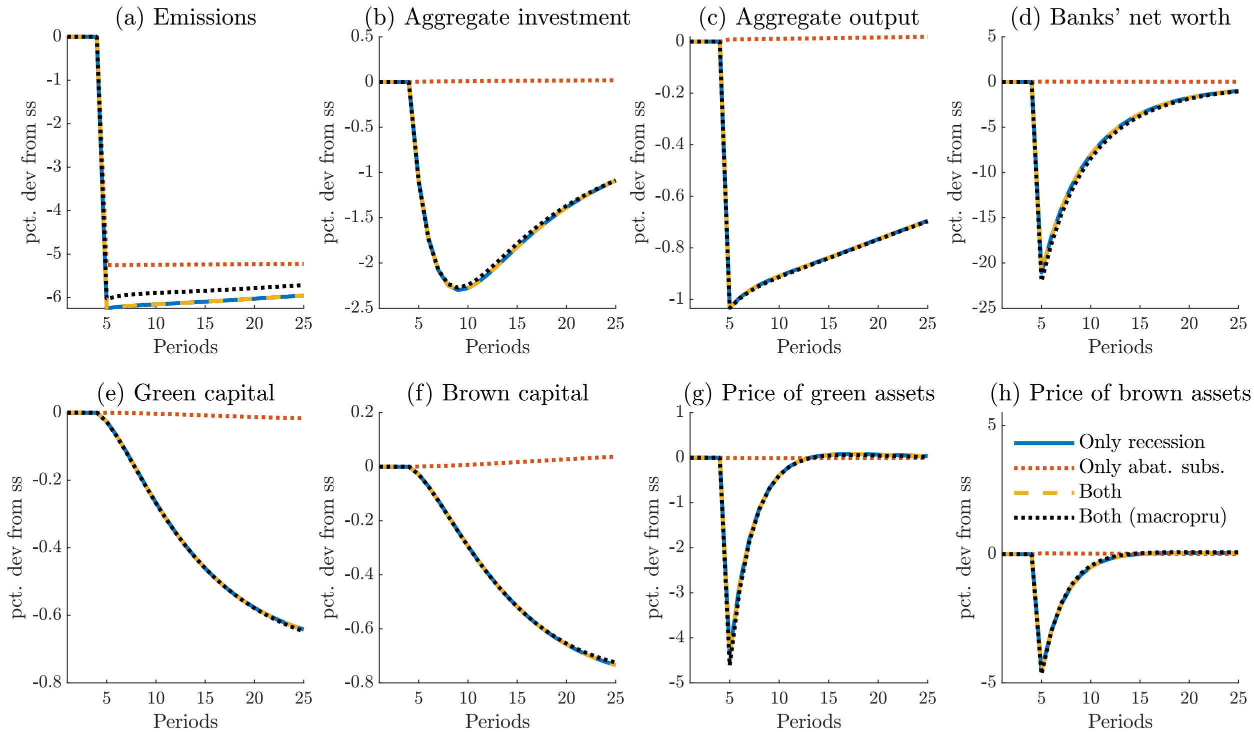
We report here the results of the simulation when other sources of transition risk hit the economy simultaneously with a negative TFP shock.

G.1 Subsidies for abatement during recession

Figure G.1 reports the dynamics of the main variable of interest in response to the simultaneous introduction of abatement subsidies and the realization of a negative TFP shock with (dotted lines) and without ex-ante macroprudential policy (solid lines). All variables are expressed in percentage deviation of their initial steady state under the two scenarios.

Section 3.1.2 reveals that the subsidy on abatement cost has a positive but small effect on aggregate output, investment, and bank net worth (Panels (c), (b) and (d) respectively). As a consequence, when this shock occurs during a recession, this channel is not sufficient to attenuate the negative effects of a TFP shock. In the presence of this source of risk compounding, the dynamics of the model are driven by the recessionary effects of a decrease in TFP. Since macroprudential policy does not mitigate these effects, it is not effective in this scenario, as revealed by dotted lines.

Figure G.1: Abatement subsidies during a recession



Note: This figure plots the transition dynamics to the combination between the introduction of abatement subsidies and TFP shocks under four scenarios: (i) only the TFP shock occurs without macroprudential policy (solid lines); (ii) only the abatement subsidy shock occurs without macroprudential policy (red dotted lines); (iii) both shocks co-occur without macroprudential policy (yellow dashed lines) and (iv) both shocks co-occur with macroprudential policy (black dotted lines) Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

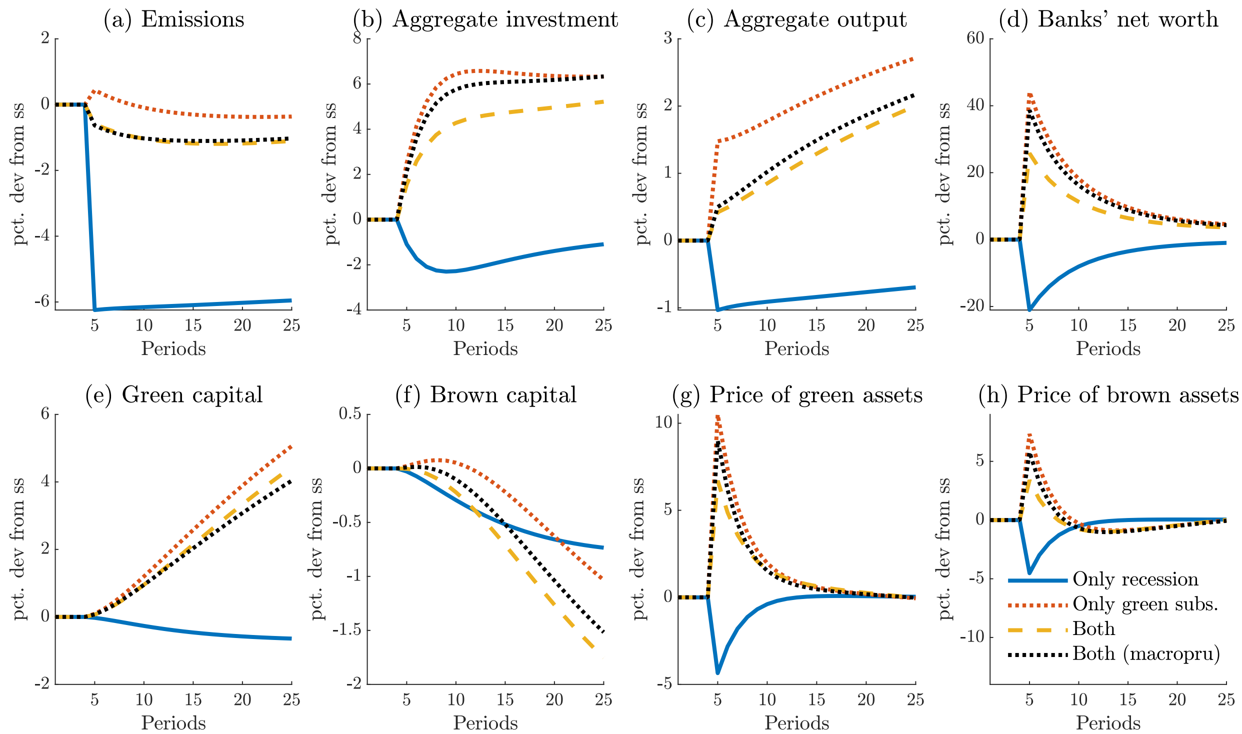
G.2 Subsidies for green producers during a recession

We now examine whether the co-occurrence of a recession and the introduction of a subsidy for green producers can trigger transition risk. We report in Figure G.2 the dynamics of the model when both shocks occur simultaneously without macroprudential policy (solid lines) and when it has been introduced before the shocks (dotted lines).

As exposed in Section 3.1.3, the introduction of a 5% subsidy for green producers represents a strong stimulus to the economy. The expansionary effects of this policy are such that they allow for mitigating the recessionary effects of a negative TFP shock: the co-occurrence of both shocks generates an increase in output (Panel (c)), investment (Panel (b)), and banks' net worth (Panel (d)) through the dynamics presented in Section 3.1.3. However, because a recession affects the economy, the stimulus generated by this policy is lower than when it is introduced in a business-as-usual period.

We now examine dotted lines to assess the effectiveness of macroprudential policy. While the tax-and-subsidy scheme is not effective in mitigating the recessionary effects of a negative TFP shock (Appendix **??**), it magnifies the positive effect of the introduction of green producers' subsidies (Figure 3) as it lowers the banks' exposure to the collapsing sector. When this policy is introduced in the presence of a TFP shock, the tax-and-subsidy scheme allows a higher increase in banks' net worth (Panel (d)) by increasing banks' exposure to the expanding green sector. Overall, it allows for a higher increase in aggregate investment and output (Panels (c) and (b)).

Figure G.2: Green producer subsidy during a recession



Note: This figure plots the transition dynamics to the combination between the introduction of subsidy for green producers and TFP shocks under under four scenarios: (i) only the TFP shock occurs without macroprudential policy (solid lines); (ii) only the green subsidy shock occurs without macroprudential policy (red dotted lines); (iii) both shocks co-occur without macroprudential policy (yellow dashed lines) and (iv) both shocks co-occur with macroprudential policy (black dotted lines) Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

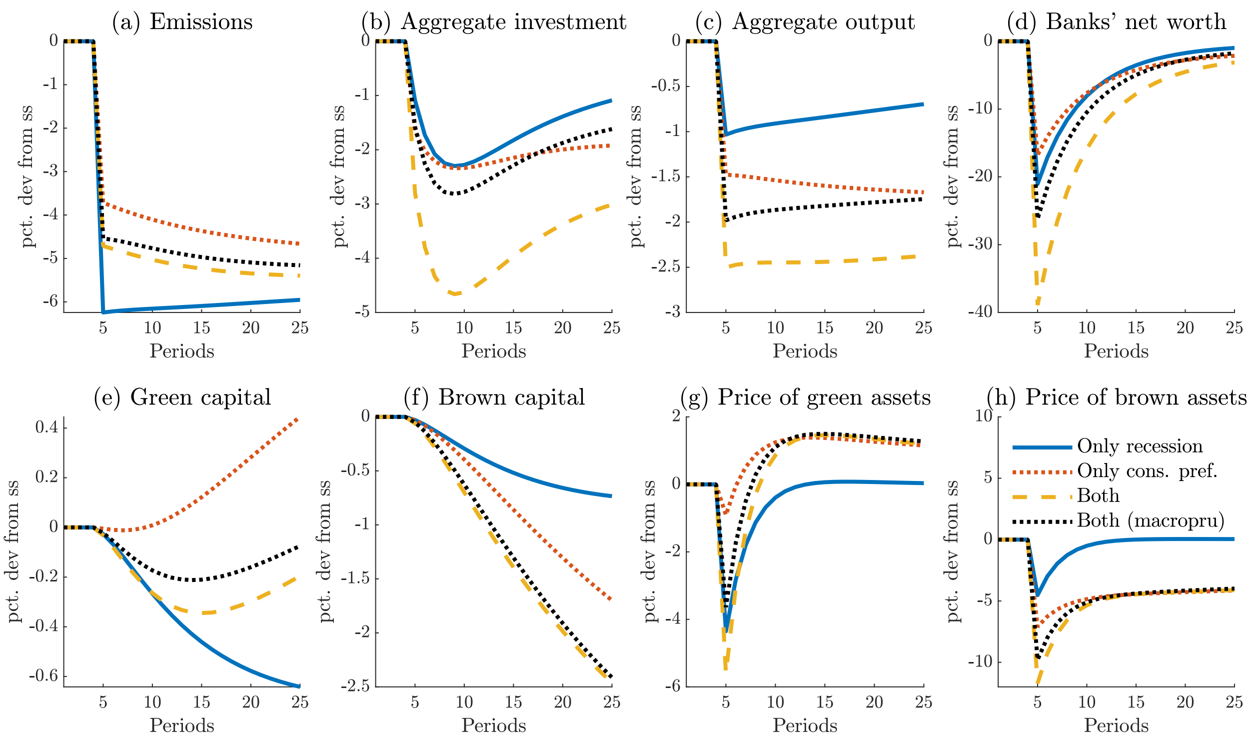
G.3 Consumer preference shock during recession

We now examine the effects of consumers' preference shocks favoring green goods when they occur during a recession. We report in Figure G.3 the dynamics of key variables when both shocks co-occur without (solid lines) and with (dotted lines) an ex-ante macroprudential policy.

The negative effects of this source of transition risk are amplified in the presence of a recession, which is stronger when both shocks occur simultaneously. The decrease in banks' net worth triggered by the preference shock described in Section 3.2.1 is amplified by the collapse in both asset prices generated by the decrease in aggregate productivity (Panels (g) and (h)). This source of risk compounding reinforces the asset stranding in the brown sector (Panel (h)). Consequently, when both shocks co-occur, banks' net worth decreases by approximately 40% (versus around 16% when the preference shock occurs in business-as-usual periods). The resulting credit tightening generates an important drop in green and brown capitals (Panel (e) and (f)). As a result, the decreases in aggregate investment and output are magnified in this scenario (Panels (b) and (c)).

We now focus on dotted lines to analyze the effect of macroprudential policy in this scenario. As a reminder, Figure 4 revealed that, when the preference shock hits the economy in business-as-usual times, macroprudential policy, by favoring the expanding sector, allowed mitigating the effects of transition risk. In this scenario, we observe the same effect. By subsidizing green asset holding, the macroprudential policy attenuates the decrease in green capital (Panel (e)) and therefore, the collapse in green asset prices (Panel (g)), allowing a lower decrease in banks' net worth, aggregate investment and output (Panels (d), (b) and (c), respectively).

Figure G.3: Consumer preference shock during a recession



Note: This figure plots the transition dynamics to the combination between the preference shock among consumers and TFP shocks under under four scenarios: (i) only the TFP shock occurs without macroprudential policy (solid lines); (ii) only the consumer preference shock occurs without macroprudential policy (red dotted lines); (iii) both shocks co-occur without macroprudential policy (yellow dashed lines) and (iv) both shocks co-occur with macroprudential policy (black dotted lines) Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.

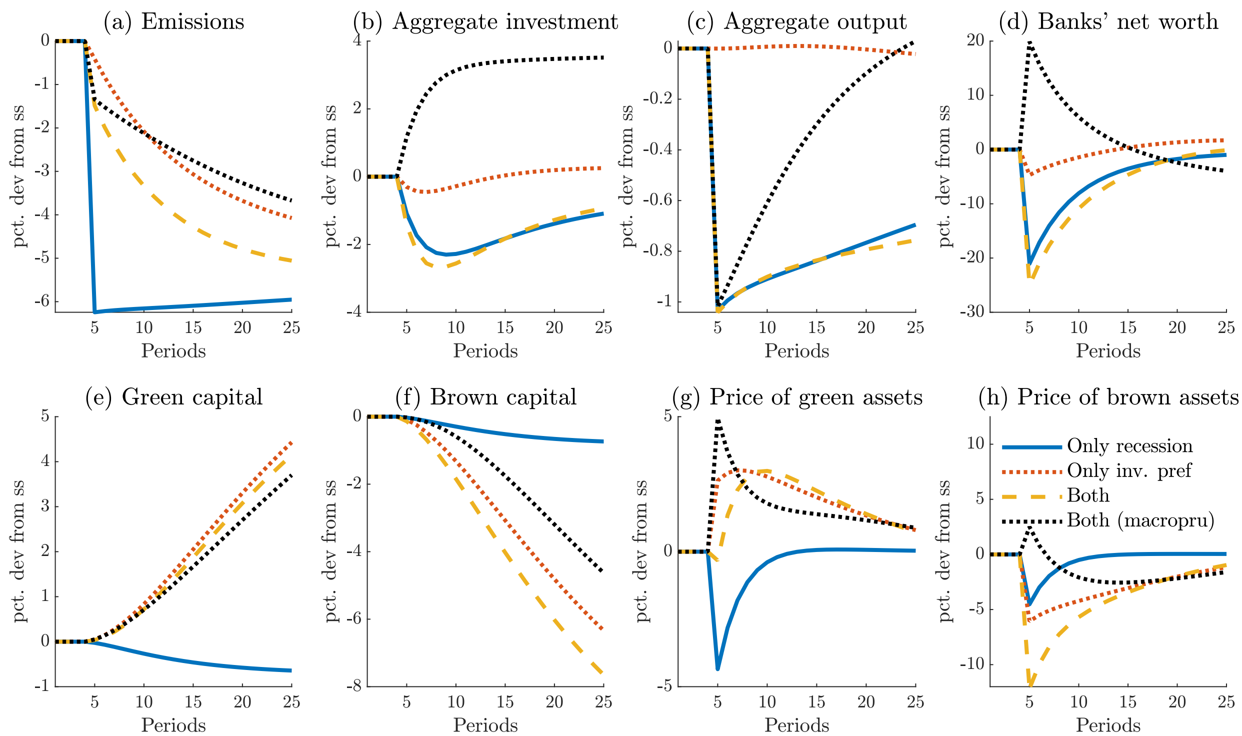
G.4 Investor preference shock during recession

We assess here the economy's response when it simultaneously faces a recession and an investor's preference shock reducing emissions by 5%. Figure G.4 plots the dynamics when both shocks co-occur with (dotted lines) and without (solid lines) ex-ante macroprudential policy. All the variables are expressed in percentage deviation from their initial steady state, under each scenario.

As exposed in Section 3.2.2, investors' preference shock generate a decrease in banks' net worth, which is here magnified by the presence of the negative TFP shock (Panel (d)). Besides, an investor's preference shock occurring at a business-as-usual period has a limited (positive) effect on aggregate investment and output (Panels (b) and (c)) but when this shock hits the economy during a recession, the effects of the recession dominate: aggregate investment and aggregate output collapse (Panels (b) and (c)).

We explore here the effects of macroprudential policy by reporting in dotted lines the dynamics when both shocks co-occur with ex-ante macroprudential policy. As a reminder, when the investor's preference shock occurs in a business-as-usual period, the presence of green macroprudential policy amplifies the expansionary effects of this shock (Figure 5). Therefore, when the shock occurs during a recession, the macroprudential policy allows mitigating the negative effect of this risk compounding. By increasing the banking sector's exposure to the green sector, which further increases following the shock, the tax-and-subsidy scheme generates an increase in banks' net worth (Panel (d)) generated by a valuation of both assets (Panel (g) and (h)). As a consequence, banks' ability to finance the economy is enhanced, triggering an increase in aggregate investment (Panel (b)) and mitigating the drop in output (Panel (c)). Overall, green macroprudential policy is effective when the preference shock occurs during a recessionary period and attenuates the negative effects of this source of transition risk.

Figure G.4: Investor preference shock during a recession



Note: This figure plots the transition dynamics to the combination between the preference shock among investors and TFP shocks under four scenarios: (i) only the TFP shock occurs without macroprudential policy (solid lines); (ii) only the investor preference shock occurs without macroprudential policy (red dotted lines); (iii) both shocks co-occur without macroprudential policy (yellow dashed lines) and (iv) both shocks co-occur with macroprudential policy (black dotted lines) Deviations are calculated relative to the respective initial steady states. Each simulation begins at the steady state with no shock under the given model.