NBER WORKING PAPER SERIES

FISCAL POLICY AND TRANSITION RISK

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Working Paper 35202
http://www.nber.org/papers/w35202

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
May 2026

We thank Don Fullerton, Marc Hafstead, and seminar participants for very helpful comments. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

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NBER Working Paper No. 35202
May 2026
JEL No. G21, H23, Q54, Q58

ABSTRACT

We study how climate policy can interact with distortionary fiscal policy and potentially lead to transition risk. Using an environmental dynamic stochastic general equilibrium model that features financial frictions and preexisting labor and capital taxes, we simulate a carbon tax and an abatement subsidy under different scenarios for returning carbon tax revenue or financing the subsidy. We find novel policy implications and important differences between the carbon tax and the subsidy. Under both policies, transition dynamics can differ sharply from long-run outcomes. For the carbon tax, transition dynamics depend on both financial frictions and the choice of revenue recycling. For the abatement subsidy, distortionary financing can generate contractionary transition dynamics, because of financial frictions. Macroprudential policy can mitigate transition risk under the carbon tax but has little effect under the subsidy.

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1 Introduction

Climate change is a significant threat to human livelihood, and policy responses are necessary to avoid major downside risk. Policy options vary but often take the form of subsidies to "green" technologies or taxes on carbon emissions. Both of these types of policies have government revenue implications – subsidies need to be paid for, and carbon tax revenues need to be spent. Lump-sum taxes are generally not available and lump-sum revenue returns are not widespread. These climate policies generally interact with preexisting fiscal policies like labor and capital taxes. Tax interactions can have significant implications not just in the long run but also along the transition to a low-carbon economy, especially in presence of imperfect financial markets and the potential realization of transition risk. By transition risk we refer to the economic and financial disruptions along the transition to a low-carbon economy, including policy-induced changes in output and investment. Transition risk is a major concern for central banks and financial surveillance authorities.[1]

The relationship between environmental policy and preexisting fiscal policies has been studied in the literature primarily with static public finance models, including prominent examples such as Bovenberg and De Mooij (1994) and Bovenberg and Goulder (1996). We refer to this stream of work as the "double dividend literature," named for the hypothesis that there are efficiency gains from using pollution tax revenue to reduce preexisting distortionary taxes. Meanwhile, studies of transition risk arising from climate policy shocks have typically been conducted using environmental dynamic stochastic general equilibrium (E-DSGE) models, including Diluiso et al. (2021) and Carattini, Heutel and Melkadze (2023). These papers generally ignore preexisting fiscal policy and only model carbon taxes, not subsidies. Barrage (2020) has introduced preexisting distortionary taxes into an integrated assessment model based on DICE, and Roach (2021) and Jaimes (2025) have introduced them into E-DSGE models, though in each case without consideration of financial frictions and transition risk.

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[1] See for instance Carney (2015); ESRB (2016); Bank of England (2018); Banque de France (2019); Bolton et al. (2020); ECB (2021); Rudebusch (2021); Saldias and Panzica (2025).

The purpose of this paper is to study how carbon tax and abatement subsidy shocks interact with preexisting labor and capital taxes and affect the realization of transition risk when financial markets are imperfect. We develop and calibrate an E-DSGE model with two production sectors – polluting (brown) and non-polluting (green) – that features a frictional financial sector building on Gertler and Karadi (2011) and also preexisting labor and capital taxes. We allow for two types of climate policy: a carbon tax or a subsidy to pollution abatement. A carbon tax generates revenues; a subsidy requires revenues from other sources. For each policy, we allow for three different strategies for recycling the tax revenues or financing the subsidies – either through a lump-sum tax or transfer, through adjusting the labor tax, or through adjusting the capital tax. Our model also allows financial regulators to anticipate transition risk and introduce green macroprudential policy. Macroprudential policy refers to regulations designed to ensure the stability of the entire financial system and the economy. We model macroprudential policy as taxes or subsidies on banks' assets, and we allow them to differ between brown or green assets. The objective of this regulation is to lower the banks' exposure to brown assets before climate policy is introduced.

We simulate how climate policy affects the economy in both the short run and the long run, paying attention to when financial frictions cause the policy to trigger transition risk, and how the choice of revenue return matters. In essence, we examine how policy design can mitigate or exacerbate transition risk, depending on the options available to policymakers, given the constrained political reality of both climate and macroprudential policymaking.

Our results show how the potential for transition risk depends on the design of climate policy, the choice of financing or revenue return, the presence of financial frictions, and macroprudential policy. We begin by presenting some results that are consistent with the earlier double dividend and E-DSGE literatures. For example, we show, both in the steady state and in the transition, that imposing a carbon tax and recycling revenues by cutting labor or capital taxes is less distortionary than recycling via a lump-sum transfer. Our main results, however, are about how this well-known tax interaction effect is altered by the presence of financial frictions during the transition period. A theme running through all of our novel findings is that, once preexisting fiscal distortions are taken into account, transition effects differ sharply between carbon tax shocks and abatement subsidy shocks. As a result, our analysis provide perspective to existing findings for carbon tax shocks and extends the literature to abatement subsidies, for which comparable benchmarks are largely absent.

We find three sets of novel results. First, we find that fiscal distortion and tax interaction effects along the transition path can be quite different than those found in previous, static tax interaction models. In particular, for the abatement subsidy's transition path, we find that a reduction in output arises only when the subsidy is financed by increasing distortionary taxes, though the steady-state outcome does not reveal this.

Second, we focus on the role of financial frictions by comparing the transition results in models with and without those frictions. Here again we find important differences between the carbon tax and abatement subsidy shocks. For the carbon tax shock, financial frictions exacerbate the magnitude of transition effects, and their quantitative importance is comparable to that of the revenue-return choice. By contrast, for the abatement subsidy shocks, detrimental transition effects emerge only in the presence of financial frictions. In particular, when the subsidy is financed through tax increases, output declines along the transition only in the frictional economy, while it increases in the frictionless case.

Third, we examine whether ex-ante green macroprudential policy can mitigate the effects of transition risk. For the carbon tax shock, macroprudential policy is effective when revenues are returned lump-sum or through cutting the labor tax, confirming previous research (see Carattini, Heutel and Melkadze 2023). The magnitude of the effect of macroprudential policy in these cases is about the same as the magnitude of the effect of the choice of revenue return itself. Hence, our results on carbon taxes point to two alternative policy margins with comparable quantitative effects, noting that in some contexts the use of either approach may be limited by political constraints. But for the abatement subsidy shock, macroprudential policy has almost no effect on any outcomes along the transition. Given that green subsidies seem to be more popular and common than carbon taxes, this result has important real-world policy implications: the macroprudential policies that the literature has recommended to respond to the potential transition risk from climate policy actually have no effect for the most common climate policies.

We contribute to two strands of literature. We speak to studies examining the potential role of transition risk and corresponding policy solutions, in particular with E-DSGE models.[2] Our unique angle is the consideration of fiscal policies and how the interaction between climate and fiscal policies influences the magnitude of a financial recession, which in the presence of frictional financial markets can emerge even with modestly ambitious climate policy. We are also among the first in this literature to study climate policies other than a carbon tax, in our case an abatement subsidy. We contribute to the literature and policy debate by assessing whether there are ways to design climate policy that mitigate or exacerbate transition risk. The design of climate policy is shaped by a variety of factors, including of political nature. We find that different policy designs lead to considerably different outcomes. Policymakers face trade-offs between the potential realization of transition risk and designing climate policy as they please.

We also add to research on the role of preexisting distortions on the design of environmental policy, i.e., the double dividend literature, across methodologies. Relative to the literature on the interaction between environmental policy and preexisting taxes in the tradition of Bovenberg and De Mooij (1994) and Bovenberg and Goulder (1996), our model contributes by including dynamics, allowing us to study the transition to a low-carbon economy. While some computable general equilibrium models (e.g. Goulder et al. 2010, 2019), other E-DSGE models (e.g. Roach 2021; Jaimes 2025), and integrated assessment models (e.g. Barrage 2020) in this literature are also dynamic, they are built to address different research questions. Neither of the two

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[2] For example, Diluiso et al. (2021); Carattini et al. (2023); Comerford and Spiganti (2022); Giovanardi and Kaldorf (2026); Carattini et al. (2024). See Annicchiarico et al. (2021) for a review of the growing E-DSGE literature.

papers that incorporate distortionary fiscal policy in an E-DSGE model and are thus similar in the ability to analyze shocks (Roach 2021; Jaimes 2025) feature a financial sector or financial frictions, and so they cannot be used to study transition risk. Further, while each of these two papers includes climate policy, neither model unanticipated climate policy shocks, and instead focus on responses to other types of shocks (abatement cost shocks and government spending shocks in Jaimes 2025 and productivity and energy price shocks in Roach 2021). Our model is uniquely tailored to examine short- to medium-term effects from climate policy shocks and the realization of transition risk, given its quarterly resolution and frictional financial sector, and to guide policymakers accordingly.

2 Model

We model a closed economy consisting of a representative household, a government, and four types of firms – financial intermediaries (banks), capital producers, and two non-financial goods-producing firms, one of which is polluting ("brown") and one of which is non-polluting ("green"). Time is discrete and indexed by t. There is a standard environmental externality, common in the E-DSGE literature, where the brown firm's output affects a pollution stock and overall productivity. There is also an inefficiency from financial market frictions, based on the specification in Gertler and Karadi (2011) and used in previous E-DSGE models including Diluiso et al. (2021) and Carattini, Heutel and Melkadze (2023). Finally, the model features preexisting distortionary taxes on capital and labor. The model thus features three distortions: two types of market failures – a pollution externality and the frictions in the financial sector – plus the preexisting fiscal policy distortions.

We consider two types of climate policies into this economy. First is a carbon tax, which is the standard way to model climate policy in E-DSGE models, usually with revenues redistributed lump sum. Carbon pricing currently covers about a third of global greenhouse gas emissions, at different levels of stringency, across more than 70 jurisdictions, including several in the United States (World Bank 2025). Second is a subsidy to the abatement costs that polluting firms face. The Inflation Reduction Act, for instance, provided subsidies (or tax credits) for carbon capture, the production of renewable electricity, the reduction of methane leaks, or the adoption of electric vehicles. Several of these policies have been adopted by subnational and national governments across the globe. However, this second climate policy has not been modeled in the E-DSGE literature, and because it is a subsidy rather than a tax, examining its financing and interaction with preexisting distortions is key. We also model macroprudential policy as taxes or subsidies on banks' assets.[3]

The model is closely related to that presented in Carattini, Heutel and Melkadze (2023), but with key extensions to address the novel research questions at the core of this paper. Such key differences include the introduction of preexisting labor and capital taxes, modeling both carbon taxes and subsidies, and allowing for policy financing (either the return of carbon tax revenue or the sourcing of subsidy funds) to be other than just lump sum. In this section, we briefly summarize the key features of the model relevant for this study, while we relegate the full description to Appendix Section A and the calibration strategy to Appendix Section B.

2.1 Financial Sector

The source of the financial frictions potentially leading to transition risk is the presence of a principal-agent problem between bankers and lenders, modeled after Gertler and Karadi (2011). Capital is not directly rented to final goods producers, but rather it is provided through financial intermediaries (banks). The aggregate value of banks' net worth is N_t. Each bank j purchases securities from the green or brown sector $S^g_{j,t}$ and $S^b_{j,t}$, respectively, at prices Q^g_t and Q^b_t; aggregate holdings of each security are S^g_t and S^b_t.[4] The green and brown final goods producers use these securities to finance their capital acquisition from the capital-producing

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[3] Given these frictions and policy options in our model, some of our results are in the spirit of a "second-best" analysis, although we do not explicitly solve for welfare-maximizing policies.

[4] We follow the notational convention, from e.g. Gertler and Karadi (2011), of denoting the quantity of the securities by S and the price of the securities by Q.

firm.

The principal-agent problem within the banking sector is as follows. Each banker j has the ability to divert or abscond a fraction κ of the bank's total assets for personal use. If this occurs, depositors recover the remaining $1-\kappa$ fraction of the assets. Because of this exogenous possibility of a banker "running away" with the depositors' money, there is an incentive constraint that must hold in order for depositors to be willing to lend to the bank. The incentive constraint (described in Appendix Section A) always holds, so that bankers never actually divert funds. But the possibility of doing so yields the incentive constraint, and this constraint leads to the market failure from financial frictions.

The Appendix derives the following equation arising from this principal-agent problem:

$$Q_t^b S_t^b + Q_t^g S_t^g = \frac{\varphi_t}{\kappa} N_t, \tag{1}$$

where $\varphi_t \geq 1$ is the shadow value of a bank's net worth. This is the key equation capturing the inefficiency in the financial sector from the principal-agent problem. The aggregate demand for capital in the economy is the left-hand side of this equation (since capital is only provided through the financial intermediaries). It is restricted by the banks' aggregate net worth (N_t). Both the degree of the principal-agent problem κ and the shadow value of banks φ_t affect the magnitude of this relationship. This constraining equation will not have to hold in a model without these financial frictions, and thus the level of capital provided to the economy can be inefficient.[5]

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[5] It is possible to modify the Gertler and Karadi (2011) framework to allow the degree of financial frictions and the principal-agent problem to differ between loans to brown and green firms – see Diluiso et al. (2021) – though we impose that these frictions are homogeneous across assets. Alternative methods of modeling financial frictions are available, e.g. Bernanke et al. (1999). See also Giovanardi and Kaldorf (2026) for an alternative model of financial frictions in an E-DSGE context.

2.2 Brown Firm and Emissions

The brown or polluting final goods firm produces output Y_t^b. As a byproduct of output, emissions e_t are created proportional to output, though they can be reduced through spending on abatement μ_t:

$$e_t = (1 - \mu_t) Y_t^b. \tag{2}$$

The variable μ_t thus represents the proportion of emissions that are abated. Abatement is costly, costing Z_t units of the brown final good:

$$Z_t = \theta_1 \mu_t^{\theta_2} Y_t^b, \tag{3}$$

where θ_1 and θ_2 are abatement cost parameters. This specification of emissions and abatement costs is inherited from the DICE model.

2.3 Preexisting Distortionary Taxes

There are two preexisting distortionary taxes. First, the representative household pays a tax rate $\tau_{L,t}$ on its labor income from labor allocated to both the brown and the green sector. The wage rate can differ across the two sectors – w_t^b and w_t^g – but the labor income rate is the same, so that net labor income received by the household is $(1 - \tau_{L,t})(w_t^b L_t^b + w_t^g L_t^g)$, where L_t^b and L_t^g are the quantities of labor supplied to the two final goods sectors.

Second, banks – who own capital in the model – pay a tax rate $\tau_{k,t}$ on the return on capital they provide to either final goods sector. Like the labor income tax, the capital income tax is not differentiated by sector. The after-tax gross rate of return that banks receive on their loans to sector $i \in \{b, g\}$ is given by $\widetilde{R}_{k,t}^i = \frac{(1-\tau_{k,t}) r_{k,t}^i + \left(1-\delta^i\right) Q_t^i}{Q_{t-1}^i}$, where $r_{k,t}^i$ denotes the rental price of capital and Q_t^i is the price of capital.

2.4 Macroprudential Policy

We succinctly model macroprudential policy as a combination of taxes or subsidies on banks' assets, which can be differentiated between brown and green assets (as in Carattini et al. 2023). Specifically, banks pay a tax (or receive a subsidy, if negative) τ_t^i when extending loans to sector $i \in \{b, g\}$. The total cost of funding a loan portfolio $(S_{j,t}^b, S_{j,t}^g)$ is therefore given by $(1 + \tau_t^b)Q_t^b S_{j,t}^b + (1 + \tau_t^g)Q_t^g S_{j,t}^g$.

We focus on ex-ante macroprudential policy, whereby the regulator sets constant tax rates in the initial steady state, rather than macroprudential policy that varies over time or in response to climate policy[6]. When doing so, the regulator can choose tax or subsidy rates to influence the relative attractiveness of different types of loans and thereby alter banks' portfolio exposures across sectors. We interpret these macroprudential taxes or subsidies as a parsimonious way to capture a range of proposed regulatory tools, including brown-penalizing and green-supporting factors in Basel-type capital requirements (see Appendix A for details).

2.5 Climate Policies

There are two climate policies available to the regulator. First, a carbon tax $\tau_{e,t}$ is levied on the brown firm based on its emissions e_t, so that the total cost the brown firm pays in this tax is $\tau_{e,t} e_t$.

Second, the brown firm's abatement cost is subsidized at the rate $s_{z,t}$, so that the total cost the brown firm pays for abatement is $(1 - s_{z,t})Z_t$, where Z_t is the gross abatement cost defined above. The variable $s_{z,t}$ is defined as a subsidy, so that when it is positive, the brown firm's abatement cost is lowered (we will only consider positive values for both subsidies and the emissions tax).

We will model each climate policy independently in the simulations below. When we study

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[6] Therefore, $\tau_t^i = \tau^i \ \forall t$

the carbon tax, we set the subsidy to zero. However, when we study the abatement subsidies, we maintain a small but non-zero carbon tax rate, calibrated based on a business-as-usual scenario described in Appendix Section B. Without a carbon tax, the abatement subsidy at any level will have no effect since the brown firm will have no incentive to abate.

Given these preexisting taxes and climate policies, the government budget constraint is the following, where an exogenous public spending G must be financed:

$$G + s_{z,t}Z_t + T_t = \tau_{e,t}e_t + \tau_{L,t}\sum_{i=g,b} w_t^i L_t^i + \tau_{k,t}\sum_{i=g,b} r_{k,t}^i K_{t-1}^i + \sum_{i=g,b} \tau_t^i Q_t^i S_t^i. \tag{4}$$

Here T_t denotes the lump-sum transfer to households that ensures a balanced budget each period. If $T_t < 0$, then this is a lump-sum tax on households.

2.6 Revenue Recycling and Subsidy Financing Options

For each policy described above, we consider different revenue-neutral recycling or financing options. Carbon tax revenues can be returned through a lump-sum transfer, they can be used to reduce the labor tax rate, or they can be used to reduce the capital tax rate. Subsidy payments can be financed through a lump-sum tax, they can be financed by increasing the labor tax rate, or they can be financed by increasing the capital tax rate.

For example, consider the case in which carbon tax revenues are recycled through reductions in distortionary taxes. When revenues are used to lower the labor income tax, the resulting tax rate is given by $\tau_{L,t} = \tau_L - \frac{(\tau_{e,t}-\tau_e)e_t}{w_t^b L_t^b + w_t^g L_t^g}$, where τ_L and τ_e denote the initial steady-state labor income tax rate and carbon tax, respectively. Alternatively, when carbon tax revenues are used to reduce the capital income tax, the capital tax rate evolves according to $\tau_{k,t} = \tau_k - \frac{(\tau_{e,t}-\tau_e)e_t}{r_t^b K_{t-1}^b + r_t^g K_{t-1}^g}$. Finally, in the case of lump-sum transfers, both labor and capital income tax rates remain at their preexisting steady-state levels (i.e. τ_L and τ_k) and lump-sum transfers

T_t adjust endogenously to satisfy the government budget constraint in equation (4).[7]

3 Results

After calibrating to a quarterly frequency based on data from the United States economy (described in Appendix Section B), we solve the model under perfect foresight following an unexpected policy shock and present simulation results for our two policy scenarios – a carbon tax and an abatement subsidy – each under three different revenue options – lump sum, labor tax, or capital tax.

3.1 Steady State

Before getting to our main results, we briefly compare and discuss steady states before and after policy changes under different options for revenue recycling or subsidy financing. These results generally confirm earlier results from the double dividend literature and help lay the foundation for our novel contributions in the following subsections.

Table 1 presents simulation results for the case of the carbon tax shock. Each entry represents the change in the value of some variable from the initial steady state, before the carbon tax increase, to the new steady state. We run each simulation both with and without the financial frictions to see the effect of those frictions on the outcomes.

The first value in the upper-left element shows that under a lump-sum transfer of carbon tax revenues and with financial frictions, the carbon tax increase yields exactly a 10% decrease in steady-state emissions. Indeed, the carbon tax magnitude is calibrated to achieve this emissions

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[7] Appendix Section A presents an analogous formula for the abatement subsidy. Note that the lump-sum transfer T_t is pinned down each period by the balanced-budget condition as per equation (4), given the paths of policy instruments and the financing rule under consideration. Thus, T_t is still endogenously determined in simulations where distortionary taxes adjust, because of movements in in other prices and quantities that enter the government budget constraint.

decrease.[8] For the same carbon tax rate increase, the other revenue recycling options yield almost the same emissions decrease, and the financial frictions do not have a large effect on the magnitude.[9]

The second row shows that aggregate output increases slightly in the new steady state – this is because the carbon tax addresses the pollution externality and thus increases efficiency. Here, there is an appreciable difference across the revenue recycling methods. Consistent with the double dividend literature, it is more efficient (yields a higher increase in output) for the tax revenues to be returned via cuts in preexisting distortionary taxes than through lump-sum transfers. Furthermore, returning all the revenue via the capital tax is more efficient than returning it via the labor tax, consistent with the results from the IAM in Barrage (2020).

We also present how investment, the banks' net worth (in the model with financial frictions), and the stock of green and brown capital differ across the policy scenarios.

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[8] In our model, a carbon tax that achieves 10% emissions reduction in the long-run is about $4.30 per ton of CO_2. While this is quite low relative to estimates of the social cost of carbon, we are interested in shocks above expectations. Such unanticipated shocks are what matters for transition risk. Hence, we provide a lower-bound approach, where larger shocks would amplify the effects that we currently simulate.

[9] We are not standardizing the carbon tax shock magnitude so that it always achieves the exact same emissions reduction across revenue recycling options; instead we keep the exact same tax rate increase.

Table 1: Steady State for Carbon Tax: Alternative Revenue Recycling Options

	Lump sum transfer		Labor tax cut		Capital tax cut	
	Financial frictions	No financial frictions	Financial frictions	No financial frictions	Financial frictions	No financial frictions
Emissions	-10.0%	-9.97%	-9.76%	-9.72%	-9.57%	-9.53%
Aggregate output	0.13%	0.16%	0.40%	0.44%	0.60%	0.64%
Investment	-0.03%	0.01%	0.25%	0.28%	0.93%	0.97%
Banks' net worth	-0.03%	–	0.25%	–	0.93%	–
Green capital	0.20%	0.24%	0.48%	0.51%	1.16%	1.20%
Brown capital	-0.37%	-0.34%	-0.10%	-0.06%	0.59%	0.63%

Note: This table shows percent changes in the steady state values of selected variables in the economies with and without financial frictions in response to the permanent increase in carbon tax under different revenue recycling options.

Table 2 presents the same set of simulations, but with the abatement subsidy policy rather than the carbon tax. Here the revenue options reflect choices for how the subsidies are financed, not how policy revenue is returned. The magnitude of the subsidy is calibrated to achieve a 10% reduction in steady-state emissions under the lump sum transfer. This emissions reduction requires an abatement subsidy rate of 67%, quite high for such a modest reduction in emissions, especially compared to the carbon tax rate of just \$4.30 per ton of CO_2 to achieve the same goal. As with Table 1 the financing scenario does not have an appreciable effect on the magnitude of the emissions reduction.

Here, the most efficient financing option is to finance the subsidy through a lump-sum transfer rather than by increasing the labor or capital tax rates. Again, this is consistent with the double dividend literature, since in this case the need for revenue to fund the tax makes the lump-sum policy the least distortionary.

Under all policy scenarios, investment increases in the long run. Indeed, both green and brown capital increase. The abatement subsidy benefits the brown firm, raising banks' net worth and relaxing their incentive constraint, which in turn allows lending and capital to expand in both sectors.[10]

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[10] The steady-state fiscal size of the interventions differ across policies but not across revenue recycling choices. The gross fiscal flow (i.e. the magnitude of the carbon tax revenue or of the abatement subsidy expenditure) is substantially larger for the carbon tax (about 0.21% of GDP) than for the abatement subsidy (about 0.01% of GDP). The scale of the fiscal intervention is irrelevant for welfare or efficiency considerations, though it may have political economy implications (Kotchen 2025).

Table 2: Steady State for Abatement Subsidy: Alternative Subsidy Financing Options

	Lump sum transfer		Labor tax increase		Capital tax increase	
	Financial frictions	No financial frictions	Financial frictions	No financial frictions	Financial frictions	No financial frictions
Emissions	-10.00%	-9.97%	-10.03%	-9.98%	-10.05%	-9.98%
Aggregate output	0.44%	0.47%	0.41%	0.47%	0.39%	0.46%
Investment	0.44%	0.48%	0.42%	0.47%	0.35%	0.46%
Banks' net worth	0.44%	–	0.42%	–	0.35%	–
Green capital	0.43%	0.47%	0.41%	0.46%	0.34%	0.45%
Brown capital	0.46%	0.49%	0.43%	0.49%	0.37%	0.47%

Note: This table shows percent changes in the steady state values of selected variables in the economies with and without financial frictions in response to the permanent increase in the abatement subsidy under different subsidy financing options.

Taken together, Tables 1 and 2 mainly confirm the intuition and results from the large double dividend literature. Our novel results arise from considering the dynamics of the transition from one steady state to another and how they are affected by financial frictions and macroprudential policy, to which we now turn.

3.2 Transition

We first consider the transition paths for our two policy shocks under the three fiscal scenarios. Figure 1 presents simulation results for the carbon tax policy along the transition to the new steady state. As with the steady-state simulations, we calibrate the magnitude of the carbon tax such that the tax yields a 10% steady-state reduction in emissions when revenues are returned lump sum, and the magnitude of the tax rate is identical across the three recycling options. We implement the unanticipated policy change starting in period (quarter) 5.

The first panel of Figure 1 shows that, regardless of revenue recycling option, the carbon tax rate yields a nearly identical 10% reduction in emissions. This reduction is instantaneous, as firms immediately increase abatement in response to the higher tax. However, the other panels show that the choice of revenue recycling can have important differential effects elsewhere in the economy, in part following from the presence of financial frictions.

Panels b and c demonstrate that returning revenue lump-sum is the most distortionary revenue return option – it leads to the largest decrease in both investment and output over the transition. Returning carbon tax revenue through reducing preexisting tax rates mitigates the contraction and can even generate increases in aggregate investment and output.[11] Panels b and c also demonstrate differences between cutting labor taxes and cutting capital taxes. A cut in the labor tax reduces investment but increases output, while a cut in the capital tax increases

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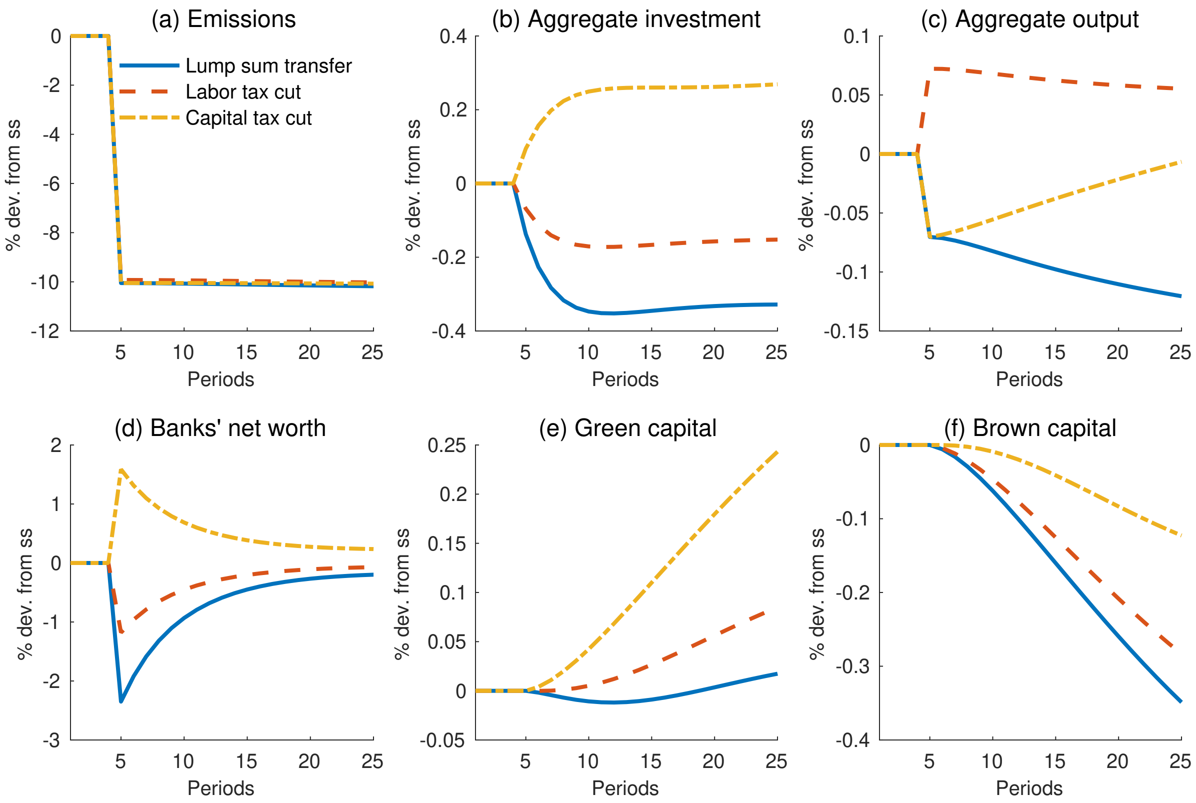
[11] This is consistent with the findings from the static double dividend literature identifying the efficiency gains from a revenue recycling effect (e.g. Bovenberg and De Mooij 1994) and with the dynamic results from integrated assessment modeling (Barrage 2020). It is likewise consistent with the findings from Jaimes (2025) in an E-DSGE model, though Roach (2021) finds that lump-sum return leads to a higher welfare outcome.

investment but reduces output, in the short to medium run. Regarding the effect on aggregate output, for the labor tax cut the benefit from the revenue recycling effect outweighs the cost from the tax interaction effect. Regarding the effect on aggregate investment, the reduction in the capital tax rate increases investment since it directly reduces the price of investment. While these results mimic some results from the previous double dividend literature, panel d shows that these results are in part affected by the presence of financial frictions. The capital tax cut increases banks' net worth, while the other two options decrease it. As a result, the levels of both green and brown capital are highest across the transition for the capital tax cut (panels e and f). Figure 1 thus tells us how these transition dynamics can fundamentally change based on the choice of revenue return, a finding absent from the previous literature examining transition risk. In the following subsection, we will more closely explore how the financial frictions impact these results, which has not been examined before in the double dividend literature.

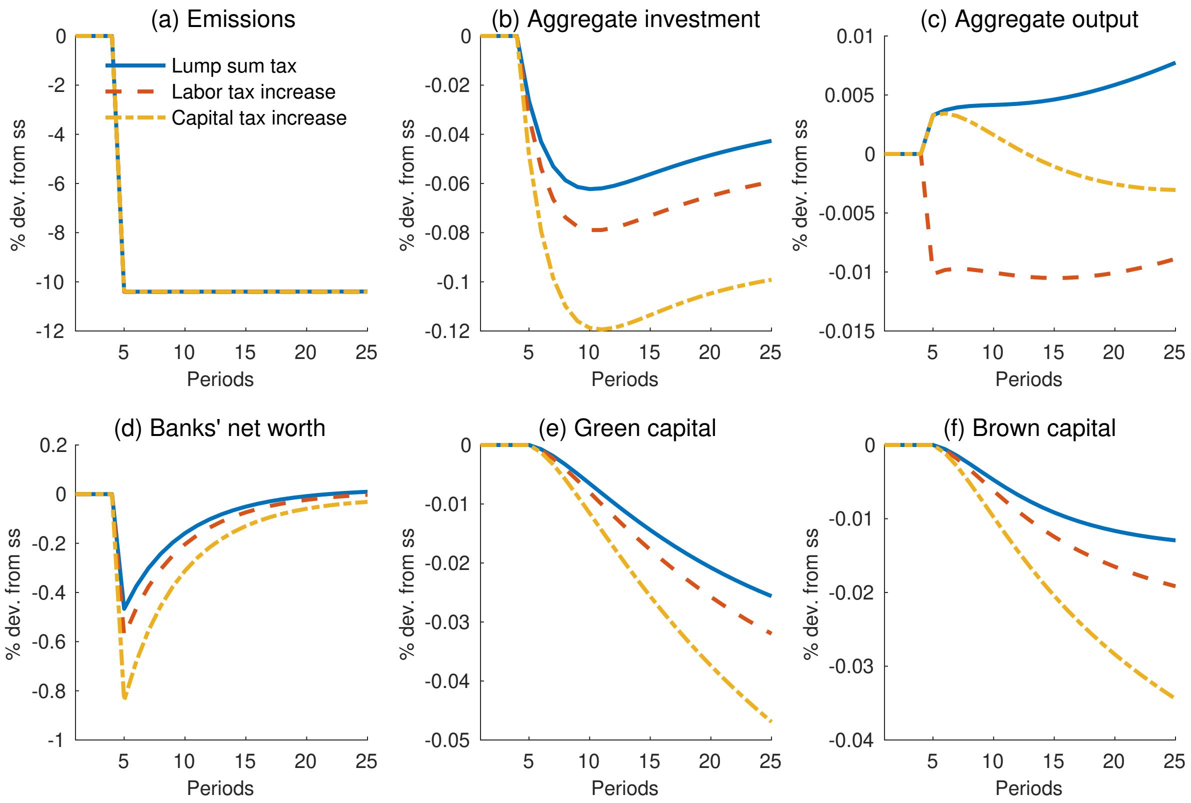
Figure 1: Carbon Tax: Alternative Revenue Recycling Options



Note: This figure plots the transition dynamics to the increase in carbon pricing under three revenue recycling options: (i) lump sum transfer (solid lines); (ii) labor tax cut (dashed line); (iii) capital tax cut (dashed-dotted 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.

But first we consider the other policy, an unanticipated introduction of a subsidy to abatement spending, presented in Figure 2. The subsidy rate is calibrated so that it achieves exactly a 10% reduction in emissions (in the new steady state) when the subsidy payments are collected through lump-sum taxes on consumers. Panel a shows that regardless of the subsidy financing option, the abatement subsidy yields almost exactly the same 10% reduction in emissions, which occur basically instantaneously. However, as in Figure 1, the remaining panels of Figure 2 show how the financing options have important differential effects elsewhere in the economy.

Figure 2: Abatement Subsidy: Alternative Subsidy Financing Options



Note: This figure plots the transition dynamics to the introduction of a subsidy to abatement spending under three subsidy financing options: (i) lump sum tax (solid lines); (ii) labor tax increase (dashed line); (iii) capital tax increase (dashed-dotted 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.

Financing the subsidy through a lump-sum tax is the least distortionary option, as the decrease in investment is the lowest (panel b), and output actually increases (panel c). Again these results confirm the presence of a tax interaction effect, pointing to the importance of considering policy financing. As previous E-DSGE models of policy have only considered lump-sum financing, and have mostly ignored abatement subsidies and focused only on carbon taxes, they have been unable to demonstrate that policy financing can have such distinctive effects on transition outcomes like investment and output. Ignoring the distortionary financing, a model with only lump-sum financing would conclude that an abatement subsidy is stimulative in the short run, increasing output (panel c). These results also show the importance of financial frictions, since panel d shows that under all financing options the subsidy decreases banks' net worth. The smallest decrease is for the lump-sum financing, while the largest is from the capital tax increase. Increasing the capital tax rate also leads to the largest decrease in investment (panel b). But, increasing the labor tax rate yields a larger and immediate decrease in output (panel c), since the effect on output from the increase in the capital tax rate takes longer to manifest due to the slower adjustment of the capital stock relative to labor. (As in Figure 1, the effects on investment and output are quite small.)

The results in Figures 1 and 2 yield important implications beyond what we see in the steady-state outcomes in Tables 1 and 2. The steady-state outcomes do not reveal how the transition, in the short and medium run, may differ from the long-run outcomes. For example, Table 2 shows that in the long run, aggregate output increases by about 0.4%, regardless of financing scheme. But Figure 2 shows that the tax increases will lead to (small) reductions in output during the transition.[12] By only focusing on the steady-state or by using static models, as is done in much of the double dividend literature, this important transition effect is overlooked.

3.3 The Importance of Financial Frictions

The other important feature that is overlooked in most of the previous double dividend literature is the importance of financial frictions. The simulations that we presented in Figures 1 and 2 are from our full model that incorporates a frictional banking sector as described above. There we could see the relevance of financial frictions by examining the effects on banks' net worth. In this subsection, we highlight the importance of those financial frictions by simulating the transitions from the previous subsection, but comparing the outcomes from our main model (which includes financial frictions) to a frictionless model.[13]

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[12] If we were to extend the simulation periods for these figures, we can confirm that eventually the new steady-state levels are reached.

[13] In this alternate model, households directly rent capital to producing firms with no agency problem, rather than using a financial intermediary. This means that in the alternate model the capital tax is statutorily paid by households rather than the bank. Still, the first-order conditions with respect to capital are isomorphic across the two models.

Figure 3 presents these simulations for the carbon tax shock. In each panel, the blue solid line represents the model with financial frictions, while the red dotted line represents the model without financial frictions. The first section presents results when the carbon tax revenues are returned lump sum, the second section when they are returned through a labor tax cut, and the third section when they are returned through a capital tax cut.

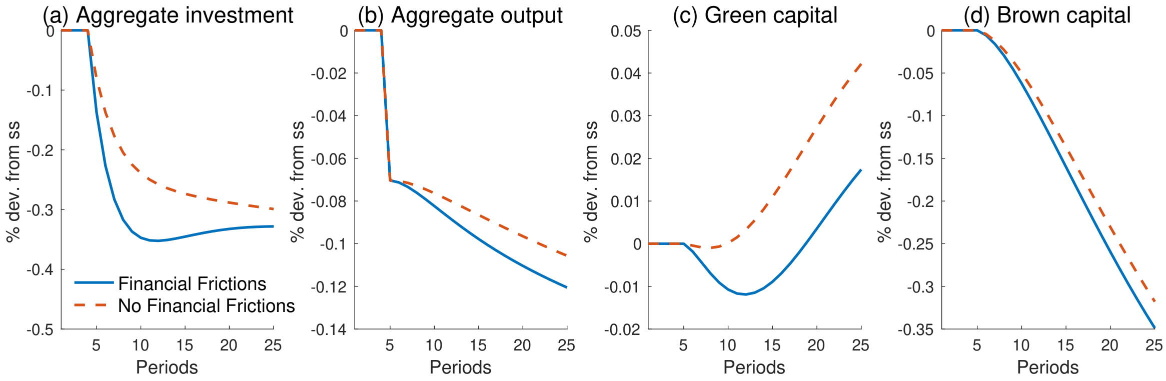
One general observation from these results is that the presence of financial frictions exacerbates the transition effects; for example, aggregate investment and aggregate output fall by more when there are financial frictions than when there are none, as reported in the first two sections. Focusing on the first section, we see that the effect from financial frictions on these outcomes is about the same as the effect of the choice of revenue return. For example, the difference in panels a and b in Figure 3 between the two curves is about the same as the difference in the aggregate investment curves from Figure 1 between the lump-sum transfer option and the labor tax cut option. The same is true for green and brown capital. In other words, the effect of financial frictions is about as important as the choice of revenue return, a finding that our model allows to uncover.

For the carbon tax shock, Figure 3 shows that financial frictions affect the magnitude of these responses, and exacerbate the transition distortions. However, for the abatement subsidy, the role of financial frictions is more substantial. Figure 4 presents the same simulations but under the abatement subsidy rather than the carbon tax. In the first section, when the abatement subsidy is financed through a lump-sum tax, we see results that are generally similar to what we see from the corresponding section in Figure 3: the presence of financial frictions affects the magnitude of the responses of these outcomes along the transition.

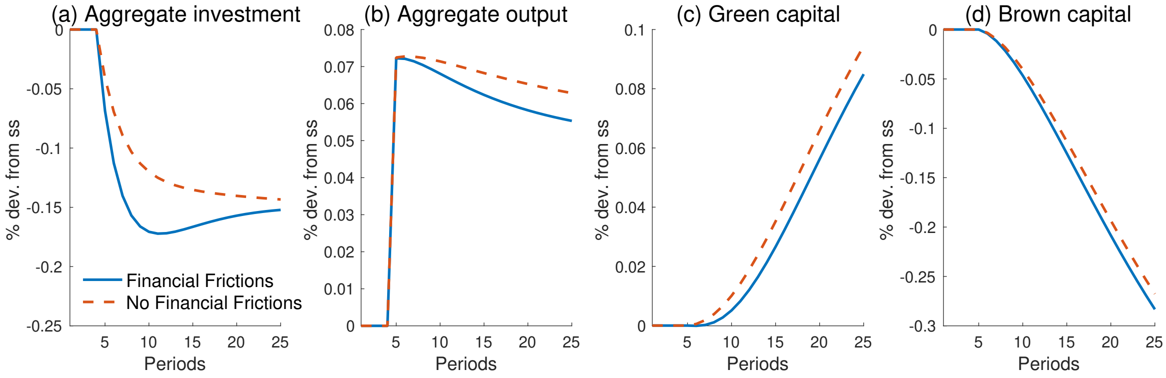
But Sections B and C of Figure 3 show us important effects from financial frictions over the transition when it comes to financing the subsidy out of preexisting distortionary taxes. We know from the steady-state results that output will increase in the long run under any revenue return scenario. But here we see how the presence of financial frictions can have a huge effect

Figure 3: Carbon Tax: Alternative Revenue Recycling Options: The Role of Financial Frictions

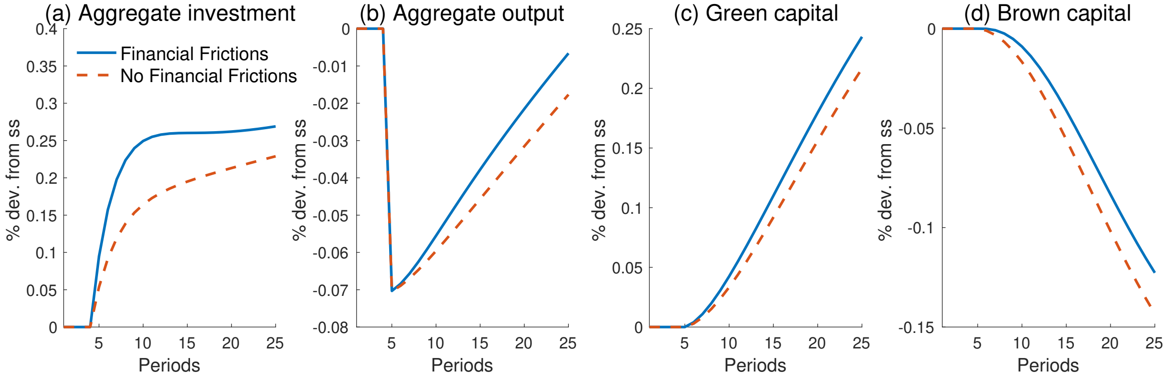
Section A. Lump sum transfer



Section B. Labor tax cut



Section C. Capital tax cut



Note: This figure plots the transition dynamics to the increase in carbon pricing under three revenue recycling options: (i) lump sum tax (Section A); (ii) labor tax cut (Section B); (iii) capital tax cut (Section C). In each case, we report the transition both with financial frictions (solid lines) and without financial frictions (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.

over the transition to that new steady state. Without financial frictions, output immediately and steadily increases on its way to its new steady-state level. But with financial frictions, output decreases over the transition – either immediately, in the case of the labor tax increase, or after a few periods, in the case of the capital tax increase. That is, the recessionary effects of subsidy occur only under financial frictions.

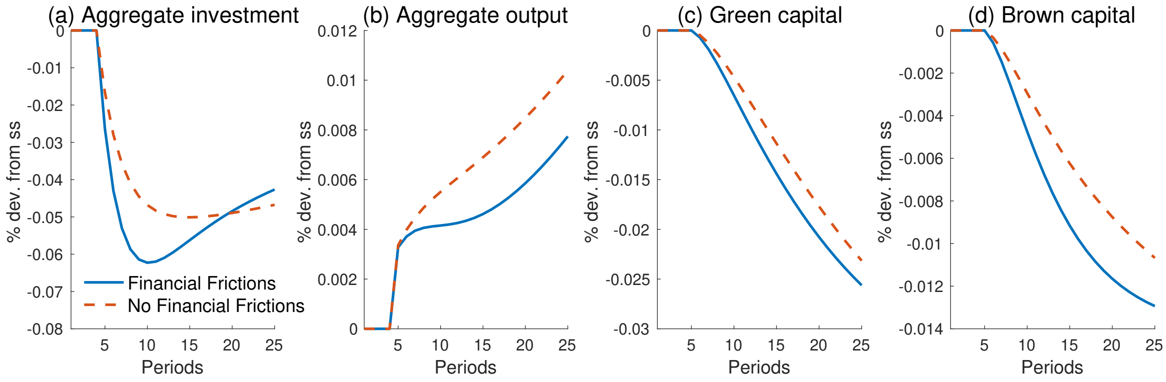
In summary, the simulations from Figure 4 discover an important revision to the standard double dividend story. This revision has not been seen in the literature before, since it is absent in models that ignore both transition effects and financial frictions. (Generally these differences are not apparent from just studying steady-state outcomes, since the impact of financial frictions in the presence of a policy shock tends to dissipate in the long run. Thus, static models cannot capture these effects.) Even relative to the E-DGSE literature that has studied transition effects and financial frictions, this effect has not been seen since that literature has not focused on the revenue return choice for policy shocks, nor the use of an abatement subsidy rather than a carbon tax.

We now explore the difference between long-run effects and transition effects by comparing welfare outcomes in the steady state to those along the transition, reported in Table 3. Each number in Table 3 is the percent change in welfare relative to the initial steady state, for the given climate policy (either the carbon tax increase or the abatement subsidy), for the given choice of financing or revenue return (either lump sum, adjusting the labor tax, or adjusting the capital tax), and both with and without financial frictions. Welfare is measured using a consumption-equivalent statistic based on the consumption-labor composite and evaluated both in the long run and along the transition. The long-run measure compares the post-policy steady state with the initial steady state. The transition measure is constructed analogously over the first 20 post-shock periods, as the cumulative deviation from the initial steady state over that horizon.

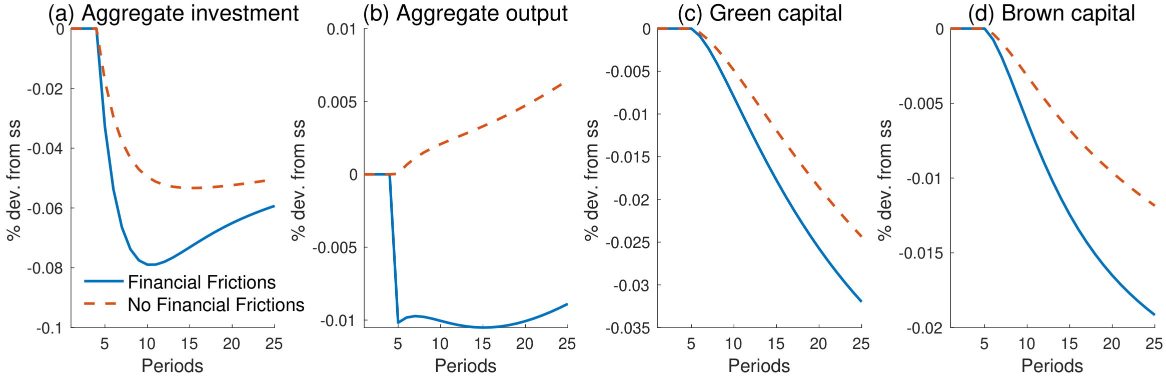
The first row in Table 3 shows that, in the long run, the carbon tax increases welfare. This is because it efficiently addresses the negative externality from pollution. The long-run increase in welfare is highest when tax revenues are recycled through cutting preexisting taxes. Likewise,

Figure 4: Abatement Subsidy: Alternative Subsidy Financing Options: The Role of Financial Frictions

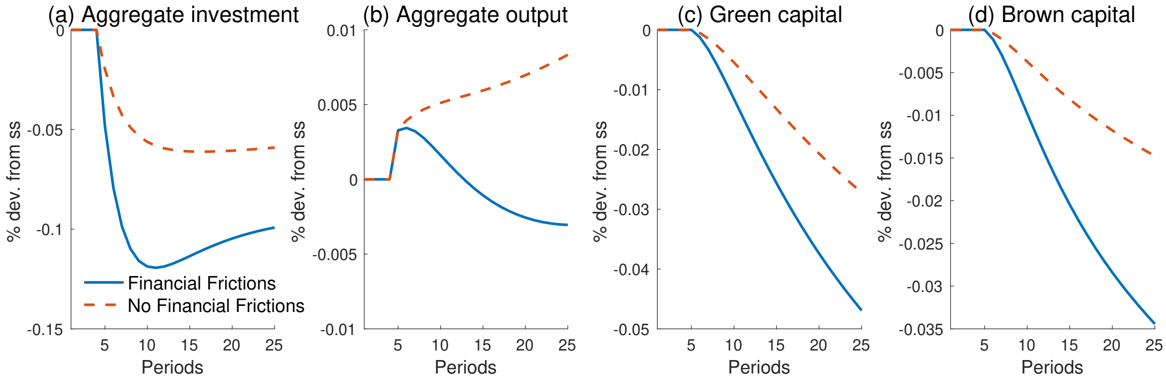
Section A. Lump sum tax



Section B. Labor tax increase



Section C. Capital tax increase



Note: This figure plots the transition dynamics to the introduction of a subsidy to abatement spending under three subsidy financing options options: (i) lump sum tax (Section A); (ii) labor tax increase (Section B); (iii) capital tax increase (Section C). In each case, we report the transition both with financial frictions (solid lines) and without financial frictions (dotted 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.

the abatement subsidy increases welfare in the long run.[14] The most efficient financing method for the abatement subsidy is also through lump-sum taxes. All of this is consistent with the double dividend literature. In the long run, the presence of financial frictions has only a very small effect on the magnitude of the welfare changes.

The story is drastically different over the transition period. For the carbon tax, returning revenues by cutting the capital tax leads to the lowest welfare over the transition period, exactly the opposite result from the long run. This difference arises because the capital tax cut leads to an increase in investment in the transition, thus reducing short-run consumption and welfare. The highest welfare increase during the transition arises from the labor tax cut. For the abatement subsidy, the capital tax increase is the only policy yielding an increase in welfare over the transition, here because of the reduction in investment and resulting increase in short-run consumption. For the transition welfare effects, the presence of financial frictions has a much larger impact. Financial frictions in all cases exacerbate the transition impacts. For example, the welfare increase for the abatement subsidy financed by a capital tax increase is eight times larger with financial frictions than without. Overall, Table 3 reinforces our main findings on how, over the transition, many of the standard results from the double dividend literature will not hold.

3.4 Macroprudential Policy

Motivated by these findings on the importance of financial frictions for tax interaction effects over the transition, we now introduce and simulate macroprudential policy, which prior E-DSGE literature has shown can reduce the extent of transition risk. We model ex-ante macroprudential policy; that is, policy that is in place before the onset of the climate policy shock, rather than macroprudential policy introduced simultaneously with the shock. We simulate an ex-ante tax on banks' brown assets and subsidy on banks' green assets, designed to be revenue neutral and

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[14] Recall that both policies are calibrated to achieve an identical 10% long-run emissions reduction. This relatively small emissions decrease accounts for the small welfare impacts.

Table 3: Long-run and Transition Welfare Impacts of Climate Policies

	Lump sum		Labor tax		Capital tax	
	Financial frictions	No financial frictions	Financial frictions	No financial frictions	Financial frictions	No financial frictions
Panel A: Carbon Tax						
Long run	0.19%	0.23%	0.31%	0.33%	0.39%	0.40%
Transition	0.78%	0.63%	1.11%	1.07%	-2.16%	-1.98%
Panel B: Abatement Subsidy						
Long run	0.33%	0.35%	0.31%	0.34%	0.31%	0.34%
Transition	-0.04%	-0.02%	-0.07%	-0.03%	0.24%	0.04%

Note: The numbers in the table represent percent changes in welfare from the climate policy relative to the initial state. Welfare is calculated for the two different climate policies, the three different revenue return or financing options, and both with and without financial frictions. Long-run welfare gain is in terms of compensating consumption variation for the post-policy steady state relative to the initial steady state. Transition welfare is computed analogously as the cumulative deviation of the consumption-labor composite over the first 20 post-shock periods relative to remaining at the initial steady state.

to reduce banks' holdings of brown assets from 40% to 32.3%. We do not model how climate policy can be used to modify these macroprudential taxes and subsidies.

Figure 5 compares the transition in response to the carbon tax shock in the economy with financial frictions, both with and without macroprudential policy, for each of the three revenue recycling options. For the lump-sum transfer, the results demonstrate how macroprudential policy can dampen the transition risk, yielding a lower contraction in investment and output with macroprudential policy (dotted line) than would be without macroprudential policy (solid line). This is due to the smaller reduction in banks' net worth (panel c) under macroprudential policy as banks are less exposed to brown assets, mitigating valuation losses when the carbon tax is implemented.[15] This mechanism operates through asset prices: macroprudential policy supports the relative price of brown assets compared to the no-policy benchmark, thereby limiting valuation losses on banks' portfolios and stabilizing their net worth during the transition.

The bottom two sections investigate how macroprudential policy interacts with the choice

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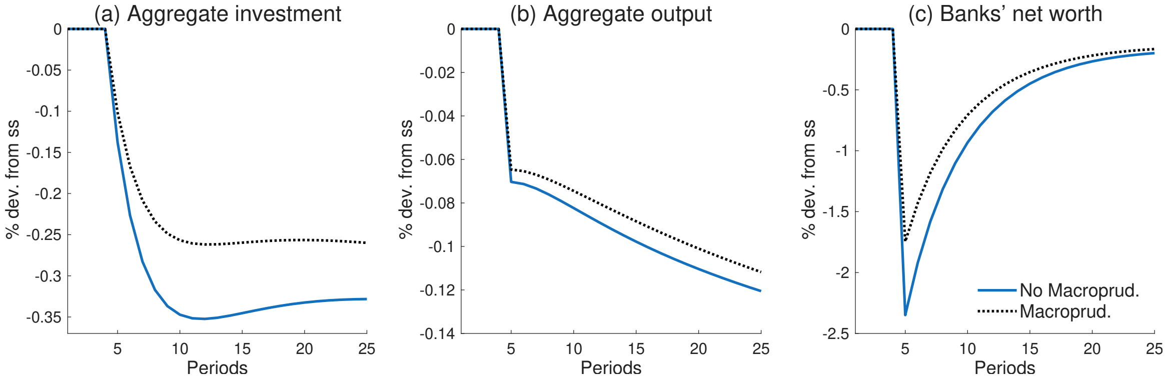
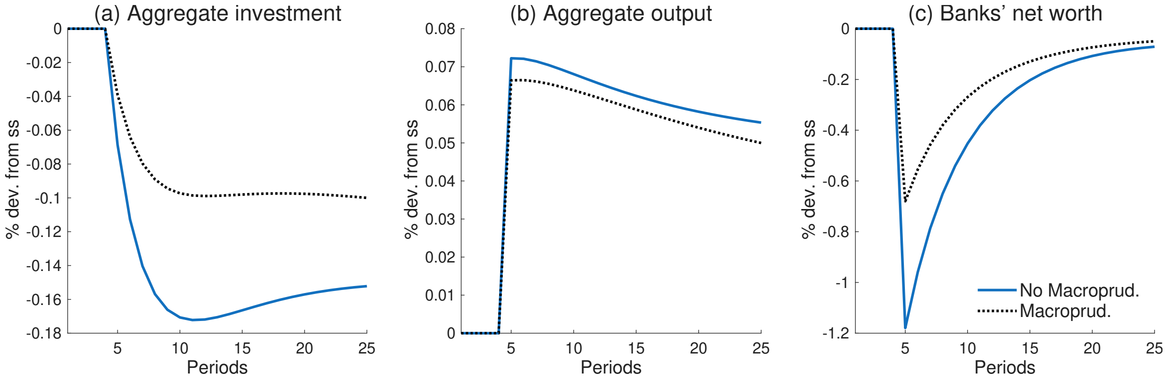
[15] This reinforces earlier findings from Carattini et al. (2023), in which macroprudential policy was studied and carbon taxation was the only policy and lump-sum return the only revenue recycling option.

Figure 5: Carbon tax: Alternative Financing Options: The Role of Macroprudential Policy

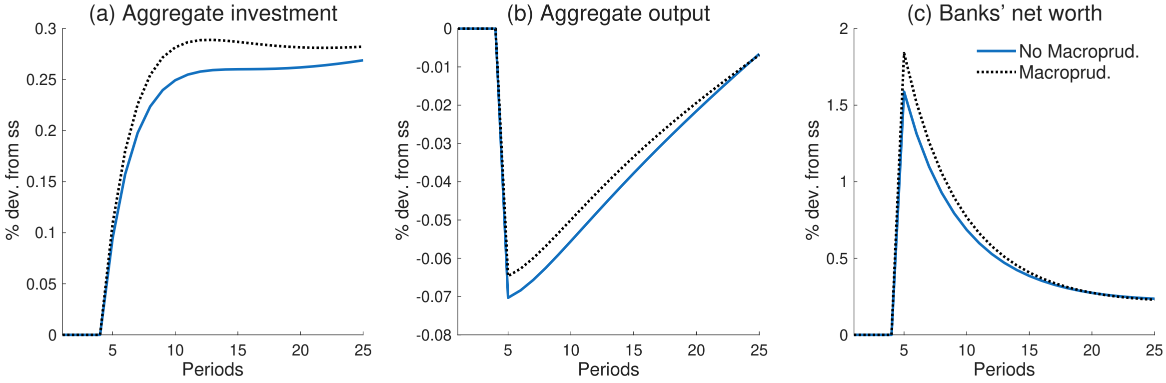
Section A. Lump sum transfer



Section B. Labor tax cut



Section C. Capital tax cut



Note: This figure plots the transition dynamics to the increase in carbon tax under three revenue recycling options: (i) lump sum transfer (Section A); (ii) labor tax cut (Section B); (iii) capital tax cut (Section C). In each case, we report the transition both without macroprudential policy (solid lines) and with macroprudential policy (dotted 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.

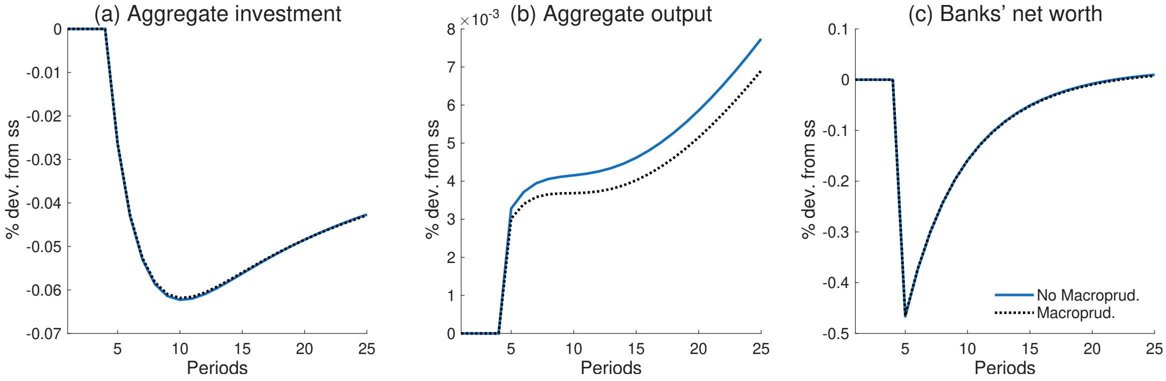
of revenue return. When the carbon tax revenue is returned through a cut in the labor tax, macroprudential policy can dampen transition risk. The decline in investment is substantially lower under macroprudential policy (panel a), due to the less-severe contraction in banks' net worth (panel c). However, the increase in output along the transition is slightly dampened with macroprudential policy (panel b), indicating that macroprudential policy will dampen both negative and positive transitional impacts of policy. The second section, when compared to Figure 1 without macroprudential policy, demonstrates a key finding: how macroprudential policy can be a substitute for a more efficient choice of revenue return. Compared to the baseline case with no macroprudential policy and with carbon tax revenues returned lump sum, either the use of macroprudential policy (shown in Figure 5) or the choice to return tax revenue by cutting the labor tax can be used to dampen negative transition effects. This finding is especially relevant for policymakers who may be constrained, and unable to use one option. Knowing that one is essentially a substitute for the other aids the flexibility of the policy toolkit.

However, we see a different story in the bottom section when we examine macroprudential policy when revenues are returned through cutting the capital tax rate. Here we see only a very small effect of macroprudential policy on outcomes along the transition. Under the capital tax cut, banks' net worth actually increases (panel c, also see in Figure 1), and the presence of macroprudential policy slightly enhances this effect, leading to a slightly larger boom in investment (panel a). But the key takeaway is that macroprudential policy does not do much over the transition when the tax revenues are returned via the capital tax. Unlike in the case of the labor tax cut, macroprudential policy here is not a substitute for the choice of revenue return.

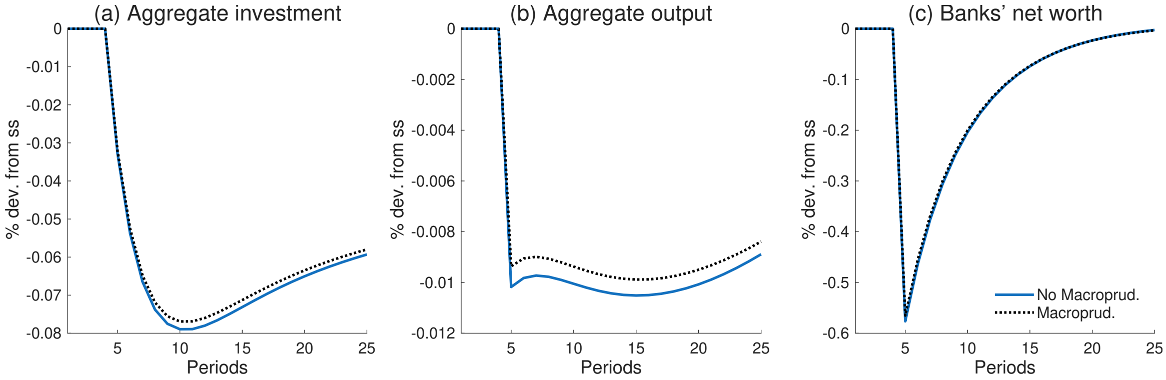
This novel result is found again in the simulations on the effects of macroprudential policy in the case of the abatement subsidy shock, reported in Figure 6. For this policy shock, macroprudential policy has almost no effect, regardless of the choice of revenue return. In contrast to the carbon tax shock, here macroprudential policy causes almost no change in the brown asset price. As a consequence, valuation effects on banks' brown asset holdings remain largely unchanged, which explains why banks' net worth (panel c), investment (panel a), and output (panel b) are almost identical with and without macroprudential policy. The explanation for why macroprudential policy does not address transition risk in the case of the abatement subsidy is that the subsidy's effects are relatively invariant to the distribution of brown versus green investment in the economy. Macroprudential policy only works through its effect on this distribution, and this distribution does impact the response of the economy to the carbon tax. For the abatement subsidy, the effect disappears.

Figure 6: Abatement Subsidy: Alternative Financing Options: The Role of Macroprudential Policy

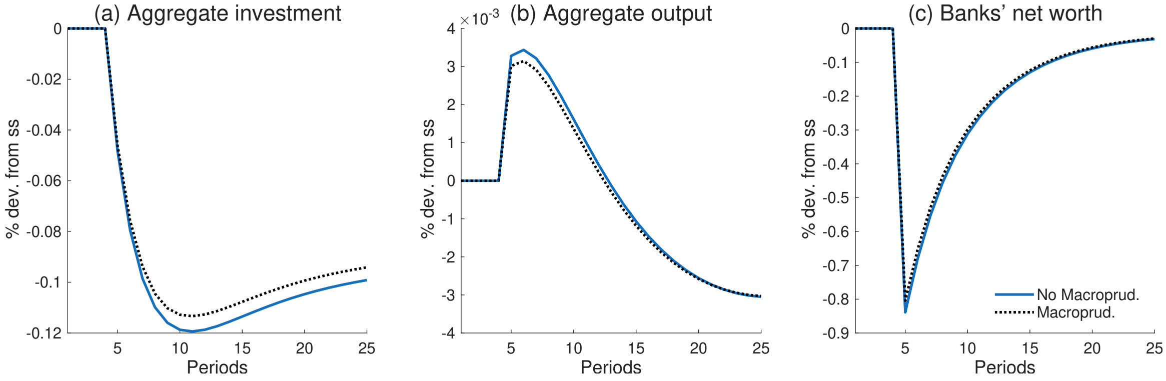
Section A. Lump sum tax



Section B. Labor tax increase



Section C. Capital tax increase



Note: This figure plots the transition dynamics to the introduction of an abatement subsidy under three revenue recycling options: (i) lump sum tax (Section A); (ii) labor tax increase (Section B); (iii) capital tax increase (Section C). In each case, we report the transition both without macroprudential policy (solid lines) and with macroprudential policy (dotted 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.

The lack of an impact on the key transition risk outcome variables of investment and output from macroprudential policy in the case of the abatement subsidy is an important and policy-relevant finding, similar to our previous finding of no impact in the case of carbon taxes with a capital tax cut. Intuitively, one might have thought that macroprudential policy can act as a substitute across the board for a more efficient choice of revenue return or financing. But for the abatement subsidy, we see this somewhat counterintuitive result: the choice of revenue return matters (as demonstrated in Figure 2), and financial frictions matter (as demonstrated in Figure 4) but the use of macroprudential policy does not matter (as demonstrated in Figure 6). Policymakers ought to take heed of this result given the fact that subsidies appear to be more relevant in current policymaking, and financing options may be constrained.

4 Conclusion

We study how the design of climate policy and the choice of revenue return or financing shape transition risk. To do so, we analyze how a carbon tax and a pollution abatement subsidy interact with preexisting labor and capital taxes in an economy with financial frictions along the transition path to a low-carbon economy. Our model is the first to capture how tax interaction effects, identified in the double dividend literature, can affect transition risk caused by a frictional banking sector. Our exercise highlights novel trade-offs across climate policy instruments, financing choices, and financial regulation. These trade-offs are especially relevant in a world where certain options – like lump-sum revenue return or ex-ante green macroprudential policy – may be unavailable. In particular, we show that transition effects can differ sharply from long-run outcomes, that financial frictions matter very differently for carbon taxes and abatement subsidies, and that macroprudential policy is not equally effective across policy instruments.

Our parsimonious model suggests several areas of further research. Our model has just a single representative agent so cannot speak to distributional effects, equity implications, or climate justice (Langot et al. 2023; Sardone 2025). We also do not model unemployment consequences of recessions, such as skill depreciation and occupational displacement (e.g. Ljungqvist and Sargent 1998; Bagliano et al. 2019; Laureys 2021; Dinerstein et al. 2022; Huckfeldt 2022) or losses in key assets (e.g. Kaplan et al. 2020). We also do not attempt to solve for "optimal" climate or macroprudential policies as in Barrage (2020) or Carattini et al. (2023). We only model two sectors so cannot consider more realistic sectoral effects (as in Dissou and Karnizova 2016; Matsumura et al. 2024; Burgold et al. 2025). Many of the other innovations that have been introduced in the E-DSGE literature could also be added to our model, including preference shocks (Benkhodja et al. 2023), price rigidities and monetary policy (Annicchiarico and Di Dio 2015), or open economies (Annicchiarico and Diluiso 2019; Carattini et al. 2024).

Still, important policy implications follow from our model. As policymakers seek to improve the design of climate policy and assess trade-offs, a focus on both long-run effects – as can be studied using integrated assessment models or static optimal tax models – as well as on short-run and transition effects – as we study in our paper – is essential. Ignoring the short-run implications of different policy design options, like the choice between a carbon tax or abatement subsidy, or the choice of policy financing or revenue return, can lead to policies that have unanticipated and potentially harmful effects. Financial instability is unwelcome per se, and it may make the implementation of future climate policy more difficult.

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A Model Equations

Here we present all the equations describing the model.

A.1 Households

The household sector is modeled following Gertler and Karadi (2011). Each household has a continuum of a unit measure, where a fraction $(1-\iota)$ of members are workers, and a fraction ι are bankers. Workers work in both non-financial firms and in brown and green production sectors. Each banker manages a financial intermediary (a bank) with dividends going to the household. Households save only by making deposits to banks.

The representative household chooses consumption C_t, bank deposits D_t, and labor hours, L_t^b and L_t^g, to maximize expected 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,

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

where w_t^b and w_t^g are wages across the sectors, R_{t-1} is the interest rate on bank deposits, Ξ_t are net dividends from banks, and Π_t denotes profits from the ownership of non-financial firms. Utility is described by $\beta \in (0,1)$, the discount factor, $\varpi > 0$, the labor disutility parameter, and $\eta > 0$, controlling the curvature of the utility function. The parameter ξ is the inverse of the Frisch elasticity of the labor hours aggregator, and ρ_L specifies the substitutability of labor hours between brown and green.

The budget constraint includes the possibility of a lump-sum transfer from or to the government T_t. It also includes a tax on labor income $\tau_{L,t}$.

We denote $M_{t,t+1} \equiv \beta \frac{U_{c,t+1}}{U_{c,t}}$ as the household's stochastic discount factor, where $U_{c,t}$ is the marginal utility of consumption ($= \left(C_t - \varpi \frac{L_t^{1+\xi}}{1+\xi}\right)^{-\eta}$). The household's first-order conditions are:

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

$$\varpi L_t^{\xi-\rho_L} \left(L_t^i\right)^{\rho_L} = (1-\tau_{L,t}) w_t^i, \quad \text{for } i = \{g, b\}. \tag{A.4}$$

A.2 Bankers

Each banker can make loans to non-financial firms by combining her own net worth with deposits from households. At time t, banker j purchases securities $S_{j,t}^i$, at price Q_t^i, issued by final good producing firms in sector $i = \{g, b\}$. The government can levy macroprudential taxes (or subsidies if negative) τ_t^i, $i = \{g, b\}$, on banks' assets. We interpret these macroprudential taxes or subsidies as being a concise way of capturing various proposed policies in banking regulation, including brown-penalizing and green-supporting policies.

The banker finances her spending with her net worth $N_{j,t}$ and new deposits $D_{j,t}$. The bank's balance sheet is

$$(1+\tau_t^b) Q_t^b S_{j,t}^b + (1+\tau_t^g) Q_t^g S_{j,t}^g = D_{j,t} + N_{j,t}. \tag{A.5}$$

Net worth evolves according to

$$N_{j,t+1} = \widetilde{R}_{k,t+1}^b Q_t^b S_{j,t}^b + \widetilde{R}_{k,t+1}^g Q_t^g S_{j,t}^g - R_t D_{j,t}, \tag{A.6}$$

where $\widetilde{R}_{k,t}^b$ and $\widetilde{R}_{k,t}^g$ denote the time t after-tax gross rate of returns on brown and green capital, respectively.

We introduce the financial friction following Gertler and Kiyotaki (2010) and Gertler and Karadi (2011). A banker has the ability to divert or abscond with an exogenous fraction κ

of total assets for personal use (i.e., transfer the funds to his/her own household). The cost of doing so is that the depositors can recover the remaining $(1-\kappa)$ fraction of assets. This possibility of absconding or "running away" means that depositors will only lend to a banker if the banker faces an incentive to not abscond.

This incentive takes the following form:

$$V_{j,t} \geq \kappa(Q_t^b S_{j,t}^b + Q_t^g S_{j,t}^g). \tag{A.7}$$

where $V_{j,t}$ is the continuation value of the bank at the end of period t. It must always be in the banker's best interests to not abscond. We impose that this constraint is always satisfied, so bankers never actually abscond. As we will show, it is this constraint that generates the inefficiencies in the financial sector.

Each period, with exogenous probability a banker exits and transfers her earnings to the household in the form of dividends and becomes a worker. The same number of workers randomly become bankers in every period. Remaining bankers maximize the expected present value of their wealth, choosing asset holdings $S_{j,t}^i$, $i=\{g,b\}$ and deposits $D_{j,t}$ to maximize

$$V_{j,t} = \mathbb{E}_t \left\{ \sum_{\widetilde{\tau}=t+1}^{\infty} (1-\gamma)\, \gamma^{\widetilde{\tau}-t-1} M_{t,\widetilde{\tau}} N_{j,\widetilde{\tau}} \right\}, \tag{A.8}$$

subject to (A.5), (A.6) and (A.7), where $M_{t,\widetilde{\tau}}$ is the households' stochastic discount factor $M_{t,\widetilde{\tau}} \equiv \beta^{\widetilde{\tau}-t} \frac{U'_{c,\widetilde{\tau}}}{U'_{c,t}}$. More details of the banker's problem and optimality conditions are presented in the Appendix of Carattini et al. (2023).

That paper shows that the bank's value function is linear in individual net worth,

$$V_{j,t} = \varphi_t N_{j,t}, \tag{A.9}$$

where $\varphi_t \geq 1$ is the shadow value of a bank's net worth. The incentive constraint can be expressed as

$$Q_t^b S_{j,t}^b + Q_t^g S_{j,t}^g \leq \frac{\varphi_t}{\kappa} N_{j,t}. \tag{A.10}$$

by combining (A.9) with (A.7). This constraint always binds given our calibration, and thus when we aggregate over the whole sector we get

$$Q_t^b S_t^b + Q_t^g S_t^g = \frac{\varphi_t}{\kappa} N_t. \tag{A.11}$$

As described in the text, this is the key equation behind the financial frictions of the model.

There is a no-arbitrage condition between green and brown loans:

$$\mathbb{E}_t \left\{ \Omega_{t+1} \left[\widetilde{R}_{k,t+1}^b - \left(1 + \tau_t^b\right) R_t \right] \right\} = \mathbb{E}_t \left\{ \Omega_{t+1} \left[\widetilde{R}_{k,t+1}^g - \left(1 + \tau_t^g\right) R_t \right] \right\}, \tag{A.12}$$

where $\Omega_{t+1} \equiv M_{t,t+1} \left(1 - \gamma + \gamma \varphi_{t+1}\right)$ is the bankers' effective stochastic discount factor.

Each new bank that enters each period receives a small initial start-up transfer $\frac{\zeta}{1-\gamma} \sum_{i=\{g,b\}} Q_t^i S_t^i$ from the households. The banking sector's net worth thus evolves according to

$$N_{t+1} = \gamma \left[\sum_{i=\{g,b\}} \widetilde{R}_{k,t+1}^i Q_t^i S_t^i - R_t D_t \right] + \zeta \sum_{i=\{g,b\}} Q_t^i S_t^i, \tag{A.13}$$

and the net dividend payouts to households are

$$\Xi_{t+1} = (1 - \gamma) \left[\sum_{i=\{g,b\}} \widetilde{R}_{k,t+1}^i Q_t^i S_t^i - R_t D_t \right] - \zeta \sum_{i=\{g,b\}} Q_t^i S_t^i. \tag{A.14}$$

A.3 Goods-Producing Firms

There are two representative goods-producing firms, one producing green goods and the other brown. Brown production includes emissions as a byproduct of production. Both firms obtain capital only through the banking sector rather than directly from households.

A.3.1 Production Technology

A pollution externality exists since the stock of pollution X_t negatively affects both firms' productivity through a damage function $d(X_t)$. Both firms have access to a Cobb-Douglas production technology with capital $\left(K_{t-1}^i\right)$ and labor (L_t^i) inputs,

$$Y_t^i = \left[1 - d\left(X_t\right)\right] A_t \left(K_{t-1}^i\right)^{\alpha^i} \left(L_t^i\right)^{1-\alpha^i}, \tag{A.15}$$

where $\alpha^i \in (0,1)$ is the capital share and A_t is the aggregate total factor productivity (TFP), evolving stochastically according to

$$\log A_t = \rho_A \log A_{t-1} + \sigma_A \varepsilon_{A,t}, \quad \varepsilon_{A,t} \sim \mathcal{N}\left(0,1\right). \tag{A.16}$$

An aggregate final consumption good Y_t is a constant elasticity of substitution aggregate of the two goods,

$$Y_t = \left[\left(\pi^b\right)^{\frac{1}{\rho_Y}} \left(Y_t^b\right)^{\frac{\rho_Y - 1}{\rho_Y}} + \left(1 - \pi^b\right)^{\frac{1}{\rho_Y}} \left(Y_t^g\right)^{\frac{\rho_Y - 1}{\rho_Y}}\right]^{\frac{\rho_Y}{\rho_Y - 1}}, \tag{A.17}$$

where $\rho_Y > 0$ is the elasticity of substitution between the two goods and π^b is a weight on the brown good. This yields the following demand functions:

$$Y_t^b = \pi^b \frac{Y_t}{\left(p_t^b\right)^{\rho_Y}}, \; Y_t^g = \left(1 - \pi^b\right) \frac{Y_t}{\left(p_t^g\right)^{\rho_Y}}, \tag{A.18}$$

where p_t^b and p_t^g are prices of brown and green goods, respectively. We choose the final consumption good Y_t as numeraire and thus normalize its price to 1.

A.3.2 Brown Firm

The specification of the pollution externality is inherited from the E-DSGE literature, which itself adapted it from integrated assessment models like DICE. The brown firm produces emissions e_t as a byproduct of production, which are proportional to its output Y_t^b but can be reduced through abatement μ_t:

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

Abating the fraction μ_t of emissions costs Z_t units of the final good governed by the following function:

$$Z_t = \theta_1 \mu_t^{\theta_2} Y_t^b. \tag{A.20}$$

As shown below, this abatement cost can be subsidized through policy.

The pollution stock X_t evolves according to

$$X_t = \delta_X X_{t-1} + e_t + e_t^{\text{row}}, \tag{A.21}$$

where e_t^{row} is emissions from the rest of the world and δ_X is the pollution stock decay rate.

A pollution externality exists because the brown firm does not internalize how its emissions affects both green and brown output through the pollution stock X_t and damages $d(X_t)$.

The brown firm purchases capital K_t^b from capital producers at market price Q_t^b at the end of period t. This purchase is financed by issuing financial claims S_t^b to banks. Each claim has the same price $\left(Q_t^b\right)$ as capital so that $Q_t^b K_t^b = Q_t^b S_t^b$. After production in period $t+1$, the firm can sell its remaining capital $\left(1 - \delta^b\right) K_t^b$ at the market price Q_{t+1}^b. The brown firm offers a state-contingent payoff $R_{k,t+1}^b$ on securities owned by the bank.

It directly hires labor L_t^b from households at wage rate w_t^b.

The brown firm is subject to an emissions tax $\tau_{e,t}$. Its profits in period t are

$$\Pi_t^b = p_t^b Y_t^b - \tau_{e,t} e_t - (1 - s_{z,t}) Z_t - w_t^b L_t^b - R_{k,t}^b Q_{t-1}^b K_{t-1}^b + \left(1 - \delta^b\right) Q_t^b K_{t-1}^b, \tag{A.22}$$

where $s_{z,t}$ is the abatement subsidy, lowering the cost to the firm of abatement spending Z_t.

The firm's first-order conditions for labor and abatement are:

$$w_t^b = \left(1-\alpha^b\right)\frac{Y_t^b}{L_t^b}\left[p_t^b - (1-s_{z,t})\theta_1\mu_t^{\theta_2} - \tau_{e,t}\left(1-\mu_t\right)\right], \tag{A.23}$$

$$\tau_{e,t} = (1-s_{z,t})\theta_1\theta_2\mu_t^{\theta_2-1}. \tag{A.24}$$

A state-contingent (pre-tax) return on brown capital consistent with the firm's state-by-state zero profit condition is given by

$$R_{k,t}^b = \frac{r_{k,t}^b + \left(1-\delta^b\right)Q_t^b}{Q_{t-1}^b}, \tag{A.25}$$

where $r_t^b = \alpha^b \frac{Y_t^b}{K_{t-1}^b}\left[p_t^b - (1-s_{z,t})\theta_1\mu_t^{\theta_2} - \tau_{e,t}\left(1-\mu_t\right)\right]$ is the net rate of return on capital.

Banks pay the capital income tax, $\tau_{k,t}$, so that the after-tax gross return the banks receive on their loans is

$$\widetilde{R}_{k,t}^b = \frac{(1-\tau_{k,t})r_{k,t}^b + \left(1-\delta^b\right)Q_t^b}{Q_{t-1}^b}. \tag{A.26}$$

A.3.3 Green Firm

The green firm also uses the financial intermediary to acquire capital, purchasing K_t^g at price Q_t^g. They also hire labor L_t^g from households at wage rate w_t^g. The green firms' optimality conditions imply

$$w_t^g = \left(1-\alpha^g\right)\frac{p_t^g Y_t^g}{L_t^g}, \tag{A.27}$$

and

$$R_{k,t}^g = \frac{\alpha^g \frac{p_t^g Y_t^g}{K_{t-1}^g} + \left(1-\delta^g\right)Q_t^g}{Q_{t-1}^g}. \tag{A.28}$$

The gross return to banks on green loans then is

$$\widetilde{R}^{g}_{k,t} = \frac{(1-\tau_{k,t})\alpha^{g}\frac{p^{g}_{t}Y^{g}_{t}}{K^{g}_{t-1}} + (1-\delta^{g})\,Q^{g}_{t}}{Q^{g}_{t-1}}. \tag{A.29}$$

A.4 Capital-Producing Firm

There is a representative firm facing competitive conditions that produces sector-specific capital, which is immobile across the two sectors. Producing capital entails convex capital adjustment costs: $I^{i}_{t},\ i = \{g,b\}$, units of sector-specific new capital goods requires $\left(1+\frac{\phi^{i}}{2}\left(\frac{I^{i}_{t}}{I^{i}_{t-1}}-1\right)^{2}\right)I^{i}_{t}$ units of the final good, where following Christiano, Eichenbaum, and Evans (2005) the parameter $\phi^{i} \geq 0$ controls the magnitude of adjustment costs.

The price of new sector-specific capital goods is Q^{i}_{t} for $i = \{g,b\}$. The capital-producing firm chooses its level of new capital to solve this profit-maximization problem:

$$\max_{\{I^{i}_{t}\}_{i=\{g,b\}}} \mathbb{E}_{0}\sum_{t=0}^{\infty}M_{0,t}\sum_{i=\{g,b\}}\left[Q^{i}_{t}I^{i}_{t} - \left(1+\frac{\phi^{i}}{2}\left(\frac{I^{i}_{t}}{I^{i}_{t-1}}-1\right)^{2}\right)I^{i}_{t}\right]. \tag{A.30}$$

The resulting first-order conditions are:

$$Q^{i}_{t} = 1+\frac{\phi^{i}}{2}\left(\frac{I^{i}_{t}}{I^{i}_{t-1}}-1\right)^{2}+\phi^{i}\left(\frac{I^{i}_{t}}{I^{i}_{t-1}}-1\right)\frac{I^{i}_{t}}{I^{i}_{t-1}}-\mathbb{E}_{t}\left\{M_{t,t+1}\phi^{i}\left(\frac{I^{i}_{t+1}}{I^{i}_{t}}-1\right)\left(\frac{I^{i}_{t+1}}{I^{i}_{t}}\right)^{2}\right\}, \quad i = \{g,b\}\,. \tag{A.31}$$

The sector-specific capital evolution equation is:

$$K^{i}_{t} = \left(1-\delta^{i}\right)K^{i}_{t-1} + I^{i}_{t},\ \text{for } i = \{g,b\}\,, \tag{A.32}$$

where δ^{i} is the sector-specific depreciation rate.

A.5 Government

The government has to finance exogenous constant expenditure G and any subsidies to abatement ($s_{z,t}$) using revenues from the carbon tax ($\tau_{e,t}$), capital and labor income taxes ($\tau_{L,t}$ and $\tau_{k,t}$), and the macroprudential taxes (τ_t^i):

$$G + s_{z,t} Z_t + T_t = \tau_{e,t} e_t + \tau_{L,t} \sum_{i=g,b} w_t^i L_t^i + \tau_{k,t} \sum_{i=g,b} r_{k,t}^i K_{t-1}^i + \sum_{i=g,b} \tau_t^i Q_t^i S_t^i. \tag{A.33}$$

Preexisting distortionary taxes adjust as follows for each climate policy scenario:

- Carbon tax:

$$\tau_{L,t} = \tau_L - \frac{(\tau_{e,t} - \tau_e) e_t}{w_t^b L_t^b + w_t^g L_t^g}; \;\; \tau_{k,t} = \tau_k - \frac{(\tau_{e,t} - \tau_e) e_t}{r_t^b K_{t-1}^b + r_t^g K_{t-1}^g}. \tag{A.34}$$

- Abatement subsidy:

$$\tau_{L,t} = \tau_L + \frac{s_{z,t} Z_t}{w_t^b L_t^b + w_t^g L_t^g}; \;\; \tau_{k,t} = \tau_k + \frac{s_{z,t} Z_t}{r_t^b K_{t-1}^b + r_t^g K_{t-1}^g}. \tag{A.35}$$

B Calibration

We calibrate the model in a manner similar to Carattini, Heutel and Melkadze (2023). While most parameters are set to the same values, some parameters that are internally calibrated to match relevant targets are re-calibrated accordingly. In addition, the model introduces new parameters–such as preexisting distrotionary taxes, the carbon tax and government spending–that also require calibrattion. We discuss in detail the calibration of parameters whose values differ from Carattini, Heutel and Melkadze (2023), as well as the newly remaining parameters. All the parameter values are summarized in Table B.1.

We choose the labor disutility parameter to match steady-state hours worked of 0.40. The labor income tax rate is set to $\tau_L = 0.27$ consistent with OECD estimates (OECD 2025). The marginal capital income tax rate is set to $\tau_k = 0.15$, in line with the estimates from the U.S. treasury.[16] We set G such that the government spending-to-GDP ratio is 20%. The preexisting carbon tax in the initial steady state is set to be equivalent to \$1.5 per ton of CO_2.

Finally, we recalibrate the parameters of the damage function (d_1 and d_2), the abatement cost parameter (θ_1), and emissions in the rest of the world (e^{row}) to hit the same targets as in Carattini, Heutel and Melkadze (2023). The resulting parameter values are summarized in Table B.1.

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[16] https://home.treasury.gov/system/files/131/EMTRs-and-EATRs-Under-CL-and-Policy-FY24.pdf

Table B.1: Calibration

Parameter	Value	Description
RBC parameters		
β	0.9975	Discount factor
η	2	Risk aversion
ξ	1	Frisch elasticity of labor hours
ϖ	5	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
G	0.20	Government spending
τ_L	0.27	Preexisting labor tax
τ_k	0.15	Preexisting capital tax
ρ_A	0.95	Persistence of aggregate TFP shocks
σ_A	0.007	Std. dev. of innovations to TFP
Environmental parameters		
θ_1	0.0336	Abatement cost function parameters
θ_2	2.6	
d_0	-0.026	Damage function parameters
d_1	$3.6784e$-5	
d_2	$1.4951e$-8	
δ_X	0.9965	Pollution decay
e^{row}	3.3547	Emissions in the ROW
ρ_Y	2	CES between 'green' and 'brown' outputs
π^b	0.332	Share of 'brown' output
τ_e	0.002	Initial carbon tax
Banking sector parameters		
κ	0.3313	Fraction of divertable assets
γ	0.972	Bankers' survival rate
ζ	0.0029	Proportional transfer to new bankers