Climate Change and the Macroeconomics of Bank Capital Regulation*

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Abstract

This paper proposes an E-DSGE model with two layers of default to study the interactions between bank regulation, climate change, and carbon taxes. Households value the liquidity services of deposits, which banks use to extend defaultable loans to clean and fossil energy firms. Capital regulation affects banks' loan supply, which in turn shapes the leverage and investment decision of the energy sector. By increasing (decreasing) the capital requirement on fossil (clean) loans, bank regulation can act as a climate policy instrument, but its efficacy is quantitatively small. In contrast, by increasing (decreasing) the clean (fossil) capital requirement, bank regulation can act as a macroeconomic stabilizer in response to carbon tax shocks. This policy reduces risk-taking incentives by clean firms and reduces aggregate default rates.

Keywords: Bank Regulation, Bank Risk-Taking, Liquidity Provision, Climate Policy, Clean Investment, Firm Risk-Taking

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1 Introduction

Limiting the adverse effects of anthropogenic climate change to a manageable level is one of the largest challenges for economic policy in the next decades. Addressing this issue is only feasible with drastic changes to production and consumption patterns, which among other things requires a shift away from fossil to clean energy sources. In this paper, we study whether this sectoral reallocation has implications for bank capital regulation. Proposing an E-DSGE model augmented by two layers of default, we show how bank regulation should address climate change and its associated risks for the financial system, explicitly allowing for differentiated capital requirements for fossil and clean loans.[1]

In the framework we are proposing, non-energy, fossil and clean energy firms can finance their activities by issuing equity or defaultable loans. Banks finance these loans by issuing deposits, protected by deposit insurance, to households, which value them for their liquidity service. The deposit insurance implies an inefficiently high level of bank risk-taking and gives rise to bank capital regulation. We allow for differentiated capital requirements on both energy firms. If regulators add a penalty capital requirement on fossil loans, banks pass the costs of higher capital requirements on to fossil energy firms who experience a deterioration in their financing conditions. This has a negative effect on their investment and, thereby, lowers aggregate emissions.

We calibrate the model to match salient empirical features of financial markets and carbon emissions and make two complementary contributions. First, we assess the suitability of bank capital regulation as a climate policy instrument. The insufficiently low levels of carbon taxes currently in place (World Bank, 2019) have sparked interest in alternative instruments that can contribute to the transition to net zero emissions. Among the most popular proposals is a differentiated bank capital requirement for loans extended to clean and fossil energy firms.[2] We show that a *fossil penalizing* factor reduces the fossil energy share and set the limits of such a differentiated policy by setting the capital requirement on fossil energy loans to 100%.[3]. Even in this case, the climate impact of this policy is smaller than even a very modest carbon tax. The induced emission reduction falls short by a factor of almost 100 relative to full abatement. We also show that differentiated capital requirements generate unintended side effects on liquidity creation, which are absent for carbon taxation. This essentially rules out differentiated capital requirements as

[1]This type of model is often used to study bank capital requirements from a macroeconomic perspective. See for example Mendicino et al. (2020) and the references therein.

[2]Financial Stability Board (2022) discusses how climate change and climate policy can affect bank regulation. See also Oehmke (2022).

[3]Starting from a baseline equity requirement of 8%, this would correspond to a risk weight of 1250%. Such a risk weight on new fossil fuel exposures is among the measures discussed within the amendment for Regulation (EU) No 575/2013 and concerns requirements for credit risk, credit valuation adjustment risk and market risk, among others

climate policy instrument.

As a second contribution, we focus on carbon taxes as climate policy instrument and study how bank capital regulation is affected by the transition to net zero. First, *anticipated* carbon taxes do not heterogeneously affect medium-run default risk in the clean and fossil sectors. They do, however, negatively affect aggregate liquidity provision to households. Clean, fossil, and non-energy goods are imperfect substitutes, such that aggregate credit demand contracts and banks reduce their balance sheets. Optimal bank regulation is slightly more lenient and requires banks to hold 7.9% of equity for each unit of loans.

In a second step, we allow for carbon tax *shocks* and find quantitatively more substantial implications for bank regulation. Since investment and loan take-up are predetermined in the shock period, the default rate of fossil firms rises on impact, while it declines for clean firms. These instantaneous effects of an unanticipated transition are well-studied in the literature. However, clean firms have an incentive to increase their risk-taking going forward, resembling a clean credit expansion. At the same time, fossil firms face deleveraging incentives. Differentiated bank capital regulation can affect the forward-looking risk-taking incentives, but not the losses on fossil loans in the impact period. It is, thus, optimal to increase (decrease) the clean (fossil) capital requirement in response to a positive tax shock.

Our model combines elements from macro-finance models with default with a climate module. Banks invest into risky corporate loans which they finance either by issuing equity or raising deposits from households. Households value deposits for their liquidity services. Following Clerc et al. (2015), banks are subject to uninsurable idiosyncratic bank risk shocks that, in reduced form, reflect the idea that banks are not always capable of extracting the full payoff from their loan portfolio. If the shock realization is sufficiently bad, the effective return on the loan portfolio is too small to repay depositors. In this case, banks do not repay deposits and fail. Depositors are protected by deposit insurance which covers the shortfall using taxpayer money. The deposit insurance put that banks exert on the government implies that banks do not voluntarily finance loans with equity.[4] Bank risk-taking introduces a rationale for capital regulation in our model. Tighter bank

[4]Rationalizing bank capital requirements by a deposit insurance put goes back at least to Kareken and Wallace (1978). VanHoose (2007) provides a comprehensive summary of early theories of bank capital regulation. Pennacchi (2006) demonstrates that deposit insurance is critical to bank liquidity provision but that it also creates moral hazard. Likewise, interpreting bank deposits as safe assets goes back at least to Gorton and Pennacchi (1990), while money in the utility specifications have been used extensively since the contribution by Poterba and Rotemberg (1986). Making households value the liquidity service of bank deposits has become a commonly used feature in many macro models of the banking sector, see also the discussion in Begenau (2020). Qualitatively, this result obtains with either liquidity premia on bank deposits or a deposit insurance put. Having both frictions will imply quantitatively desirable features of the model.

regulation decreases the bank failure probability and liquidity creation. Since banks have to finance loans with costly equity, higher capital requirements also reduce loan supply to firms ceteris paribus.

By affecting loan supply, bank regulation also changes the risk-taking decision of firms vis-a-vis banks: Firms invest into capital either by obtaining long-term random maturity loans from banks or by issuing equity. By making firm owners more impatient than households, firms have an incentive to use debt financing. We furthermore assume that their production technology is subject to uninsurable idiosyncratic productivity shocks. Due to limited liability, firms default on their loan obligations whenever their current revenues fall short of the due loan repayment. Corporate default entails a resource loss: the optimal loan issuance is then determined by firm owners' relative impatience, resource losses of default, and banks' loan supply. Since banks' willingness to pay for a loan increases if capital requirements decline, a lenient capital requirement also improve borrowing conditions for firms. The implied increase in loan prices incentivizes firms to issue more loans, invest more, and choose a higher leverage ratio, which will ultimately lead to more frequent loan delinquencies.[5] In our framework, the optimal capital requirement, absent environmental concerns, is determined between facilitating liquidity creation by banks and minimizing resource losses from corporate default.

We link this model of optimal capital requirements to climate policy by augmenting the production side of the economy with an energy sector. Specifically, there are two representative energy firms, clean and fossil. While both firms supply an energy good to final good producers - on which we impose a high elasticity of substitution - the fossil energy firm generates emissions in the production process. Emissions depreciate slowly and generate socially costly pollution, which we operationalize using a damage function specified as a relative GDP loss (Nordhaus, 2018).

In a standard calibration, we first show that a 1250% risk weight on fossil loans induces a spread on clean and fossil loans of 55bp, which is typically referred to as the *greenium*.[6] This increases the share of clean energy loans and investment, reduces emissions, but also induces deposit spreads to widen by more than 10bp. This reduction in liquidity provision is sufficiently strong to make the policy welfare-reducing. It is helpful to benchmark the climate efficacy of such a policy against carbon taxes. For example, a tax of around 5.5 dollars per tonne of carbon would imply the same share of investment into fossil technolo-

[5] This is conceptually similar to the setup in Begenau (2020). Different to her model, firms choose the default risk of corporate loans in our model, taking banks' break-even condition on the loan market as given.

[6] Our model abstracts from shadow banks, all other types of financial intermediaries or foreign lending. These alternative sources of debt-financing could induce a substitution away from bank loans and mitigate the effects of high fossil capital requirements on loan rates. Our estimates can therefore be interpreted as conservative.

gies. A tax of around 0.5 dollars per tonne already induces the same emission reduction. The reason behind this discrepancy is that fossil penalizing capital requirements merely downsize fossil energy firms but do not provide abatement incentives. Therefore, we discard differentiated capital requirements as climate policy instrument and focus on the consequences of the transition to net zero for optimal bank regulation.

We then add carbon tax shocks, which are a tractable way of capturing suddenly changing political sentiments. One could alternatively think of large natural disasters that make climate change more salient and, thereby, induce policymakers to suddenly engage in stringent climate policies.[7] Since a persistent tax shock also introduces persistent productivity differences between sectors, clean firms increase both their investment and leverage. Due to the long-term nature of loans, the increase in loan issuance by clean firms trails their investment by several quarters, such that it drops initially and increases even above the pre-shock value after a few quarters. In the terminology of Gomes et al. (2016), leverage and default risk are sticky. The opposite effect can be observed for fossil firms. By applying capital requirements that lean against the risk-taking and de-leveraging effects of clean and fossil firms, differentiated capital requirements contribute to macroeconomic stabilization. Taken together, our results indicate that (quantitatively) there is only small scope for bank capital regulation as climate policy instrument or a facilitator of climate policy. Instead, its optimal response to climate policy is motivated on more conventional macroeconomic stabilization objectives.

Our paper is structured as follows: Section 2 sets up the E-DSGE model with two layers of default. We describe our calibration in Section 3. In Section 4, we discuss the suitability of capital requirements as climate policy instrument. Optimal capital requirements in response to carbon taxes are presented Section 5. Section 6 concludes.

Related Literature. We contribute to the growing literature on interactions between financial frictions, climate change, and climate policy. There are several theoretical results on the relevance of financial frictions for the conduct of environmental or climate policy. Heider and Inderst (2022) and Döttling and Rola-Janicka (2022) show that financial frictions can impair the conduct of climate policy: if stringent carbon taxes induce inefficient liquidation of investment projects due to financial constraints, the optimal Pigouvian emission tax is lower than in the absence of financial frictions. In Fuest and Meier (2023), sustainable finance policies serve as a commitment device for carbon tax policies. Our paper also relates to Hong et al. (2023) who derive cost-of-capital wedges that are necessary to achieve net zero targets and are conceptually similar to the loan pricing wedges induced by differentiated capital requirements. Oehmke and Opp (2022)

[7] Formally, the tax shocks in our model are defined relative to a steady state tax level. However, they can also be interpreted as persistent, but non-permanent, deviations from a transition path.

show that green capital requirements are an ill-suited instrument to initiate a transition to net zero: preferential green capital requirements might even increase lending to brown firms if these are the marginal project banks can finance. On a conceptual level, the inferiority of differentiated capital requirements and its adverse side effects (relative to taxes) also relate to Davila and Walther (2022) who develop a general framework of second-best regulatory policies.

To the best of our knowledge, there is no paper studying optimal bank regulation in a quantitative E-DSGE model. A series of recent papers has however studied green-tilted central bank policies in this class of models, such as green QE (Ferrari and Nispi Landi, 2022 or Abiry et al., 2021) and green collateral policy (Giovanardi et al., 2022). These papers deliver a quantitatively similar result on the limited effectiveness of green-tilted financial policies that are similar to our results. Annicchiarico et al. (2022) propose a model with external financing constraints and discuss the macroeconomic stabilization implications of using carbon taxes and cap-and-trade policies. Using a similar setup, Carattini et al. (2021) study the effects of asset stranding on the macroeconomy. Through a financial accelerator, bank balance sheet losses impair credit supply to all firms in the economy. In their framework, macroprudential capital requirements can mitigate asset stranding and facilitate more stringent climate policy.

2 Model

Time is discrete and indexed by $t = 1, 2, \ldots$. The model features a representative household, three types of intermediate good firms, monopolistically competitive final good producers, investment good producers, banks, and a public sector levying carbon taxes and setting bank capital requirements. The intermediate firms produce non-energy, fossil and clean energy goods, respectively. While both energy goods are highly (but not perfectly) substitutable, the substitution elasticity between energy and non-energy goods is small (but not zero). Emissions of fossil energy producers accumulate into a carbon stock, which inflicts a cost on final good producers. Clean and non-energy producers do not contribute to the accumulation of emissions. The final good producer uses both types of energy goods, the non-energy intermediate good, and labor to produce the final consumption good. Investment good firms supply sector-specific investment goods. Banks raise deposits from the household to extend loans to all three intermediate good producers and invest into government bonds.

Households. We keep the household sector intentionally simplistic to maintain a focus on investment and leverage dynamics in the financial and corporate sector. The representative household inelastically supplies $\overline{n}$ units of labor at the real wage w_t and derives utility from consumption c_t and from the end-of-period real value of nominal deposits, d_{t+1}. Deposits held from time $t-1$ to t earn the nominal interest rate r^D_{t-1}. The household's time discount factor is denoted by β. The maximization problem of the representative household is given by

$$V_t = \max_{c_t, d_{t+1}} \frac{c_t^{1-\gamma_C}}{1-\gamma_C} + \omega_D \frac{d_{t+1}^{1-\gamma_D}}{1-\gamma_D} + \beta \mathbb{E}_t \left[V_{t+1}\right] \tag{1}$$
$$\text{s.t.} \quad c_t + d_{t+1} = w_t \overline{n} + (1 + r^D_{t-1}) \frac{d_t}{\pi_t} + div_t + T_t \ ,$$

where div_t collects real dividends from banks and firms, π_t is gross inflation between $t-1$ and t, while T_t is a lump sum transfer from the government. Solving the maximization problem (1) yields the Euler equation for deposits

$$1 = \mathbb{E}_t \left[\Lambda_{t,t+1} \frac{1 + r^D_t}{\pi_{t+1}}\right] + \omega_D \frac{d_{t+1}^{-\gamma_D}}{c_t^{-\gamma_C}} \ . \tag{2}$$

Here, $\Lambda_{t,t+1} \equiv \beta \frac{c_{t+1}^{-\gamma_C}}{c_t^{-\gamma_C}}$ is the household's stochastic discount factor. Since deposits provide utility to households, the deposit rate r^D_t will be smaller than the risk-free rate r_t implied by the household sdf:

$$1 = \mathbb{E}_t \left[\Lambda_{t,t+1} \frac{1 + r_t}{\pi_{t+1}}\right] \ . \tag{3}$$

Banks. The representative bank extends loans l^c_t, l^f_t and l^n_t to clean, fossil and non-energy firms and holds risk-free government bonds l^b_t. The portfolio of loans and bonds is financed either with deposits d_t or equity (corresponding to negative dividends). Following Clerc et al. (2015), we assume that banks are subject to uninsurable idiosyncratic bank risk shocks μ_t, which follow an i.i.d. log-normal distribution with a mean of one and standard deviation ς_μ. Banks enter period t with nominal liabilities from deposits issued last period $(1 + r^D_{t-1})d_t$ and assets returning $\mu_t \sum_\tau \mathcal{R}^\tau_t l^\tau_t$, where $\tau \in \{b, c, f, n\}$. The type-specific nominal payoffs will be described below. If the idiosyncratic bank risk shock falls below a threshold level $\overline{\mu}_t$, banks are unable to service depositors. In this case, they transfer all their assets and liabilities to the deposit insurance agency, who covers the shortfall and pays back depositors in full.[8] Put differently, depositors are paid by

[8] Alternatively one could assume that banks always have to service deposits but receive a bailout, such that dividends are given by

$$div_t = \mu_t \sum_\tau \mathcal{R}^\tau_t l^\tau_t - (1 + r^D_{t-1}) d_t + S^{DIA}_t + d_{t+1} - \sum_\tau q^\tau_t l^\tau_{t+1} \ .$$

deposit insurance in the case of default, while banks are protected by limited liability. Banks should be interpreted in a wide sense as all institutions that are part of a deposit insurance scheme or enjoy an (implicit) bailout guarantee by the government. This is consistent with the empirical analysis in Begenau (2020), who shows that aggregate bank liabilities (including bank bonds and term deposits) are correlated with liquidity premia.

We assume that the deposit insurance agency incurs a deadweight loss from managing bank assets. The threshold for the realization of the bank risk shock is implicitly given by the return realization $\overline{\mu}_t$ that makes the bank indifferent between failure and repayment of depositors:

$$\overline{\mu}_t = \frac{(1 + r^D_{t-1})d_t}{\sum_\tau \mathcal{R}^\tau_t l^\tau_t} \ . \tag{4}$$

We assume that banks are restructured intermediately after a failure: they can extend new loans to firms and raise equity and deposits. This facilitates aggregation into representative banks. Furthermore, by allowing banks to issue equity immediately, there are no fire sale mechanisms at play in our model, which typically arise in models with external financing constraints (Gertler and Kiyotaki, 2010). In our model, we do not differentiate between inside and outside financing, but between debt and equity financing. Thus, banks do not have an incentive to accumulate equity for precautionary reasons and pay positive dividends each period, rather than following a zero dividend policy. The period t dividend is then given by

$$div_t = \mathbb{1}\{\mu_t > \overline{\mu}_t\} \left(\mu_t \sum_\tau \mathcal{R}^\tau_t l^\tau_t - (1 + r^D_{t-1})d_t \right) + d_{t+1} - \sum_\tau q^\tau_t l^\tau_{t+1} \ .$$

Since bank failures lead to deadweight losses, banks are required to finance a (potentially type-specific) fraction κ^τ_t for $\tau = \{b, c, f, n\}$ of their assets by equity. When maximizing the present value of dividends, banks have to satisfy the following constraint:

$$(1 + r^D_t)d_{t+1} \leq \sum_\tau (1 - \kappa^\tau_t)\mathbb{E}_t \Big[\mathcal{R}^\tau_{t+1} \Big] l^\tau_{t+1} \ . \tag{5}$$

Due to the immediate restructuring assumption and the i.i.d. nature of the bank risk shock μ_t, the bank problem reduces to a two-period consideration, which resembles the

If the bailout is given by the state-dependent transfer

$$S^{DIA}_t = \mathbb{1}\{\mu_t < \overline{\mu}_t\}\big((1 + r^D_{t-1})d_t - \mu_t \sum_\tau \mathcal{R}^\tau_t l^\tau_t\big)$$

that exactly covers the shortfall, period t dividends are identical to the formulation using a deposit insurance agency.

overlapping generations setup in Clerc et al. (2015):

$$\max_{d_{t+1},\{l^{\tau}_{t+1}\}} d_{t+1} - \sum_{\tau} q^{\tau}_t l^{\tau}_{t+1} + \mathbb{E}_t \left[\Lambda_{t,t+1} \int_{\overline{\mu}_{t+1}}^{\infty} \mu_{t+1} \sum_{\tau} \frac{\mathcal{R}^{\tau}_{t+1}}{\pi_{t+1}} l^{\tau}_{t+1} - \frac{1+r^D_t}{\pi_{t+1}} d_{t+1} dF(\mu_{t+1}) \right].$$

The expected loan payoff $\mathbb{E}_t\left[\mathcal{R}^{\tau}_{t+1}\right]$ depends on firm τ's loan issuance and investment via the possibility of corporate default in future periods (described below). Financing a loan by raising deposits increases bank dividends in period t by one unit. This exceeds expected discounted repayment in period $t+1$, which is given by $\mathbb{E}_t\left[\Lambda_{t,t+1}\frac{1+r^D_t}{\pi_{t+1}}\left(1-F(\overline{\mu}_{t+1})\right)\right]$, where $F(\overline{\mu}_{t+1})$ denotes the bank failure probability. This is due to (i) liquidity benefits of deposits and (ii) the risk of bank failure. This implies that, absent capital regulation, banks have no incentive to finance loans by equity and that the capital requirement will be binding in all states (see also Begenau, 2020).

Solving subject to the binding capital constraint (5), we obtain a loan pricing condition

$$q^{\tau}_t = \mathbb{E}_t \left[\left\{ (1-\kappa^{\tau}_t) \underbrace{\left(\frac{\pi_{t+1}}{1+r^D_t} - \Lambda_{t,t+1}\left(1-F(\overline{\mu}_{t+1})\right) \right)}_{\text{Deposit Financing Wedge } \Xi_t} + \underbrace{\Lambda_{t,t+1}\Big(1-G(\overline{\mu}_{t+1})\Big)}_{\text{Banker sdf } \overline{\Lambda}_{t,t+1}} \right\} \frac{\mathcal{R}^{\tau}_{t+1}}{\pi_{t+1}} \right]. \quad (6)$$

Details are relegated to Appendix A. Equation (6) shows that both the deposit insurance put and liquidity services affect the pricing of loans via bankers' stochastic discount factor. The deposit financing wedge Ξ_t reflects the benefit of financing a loan through deposits $r^D_t < r_t$ due to their liquidity benefits. It also reflects the deposit insurance put: the expected repayment obligation in period $t+1$ of raising one unit of deposits in period t is only $1-F(\overline{\mu}_{t+1})$. Both benefits of deposit financing are weighted by the deposit financed share $(1-\kappa^{\tau}_t)$ of the loan. This direct effect implies that loan prices increase if capital requirements are relaxed.

There is also a second indirect effect operating through the expected bank profitability conditional on not failing $(1-G(\overline{\mu}_{t+1}))$.[9] Banks lose control of their assets to the deposit insurance agency in case of a failure. Banks take their own failure risk into account when banks price loans: loan payoffs are discounted more strongly. Stringent capital requirements, therefore, also have a positive effect on loan supply by decreasing $(1-G(\overline{\mu}_{t+1}))$. This resembles the "forced safety effect" studied by Bahaj and Malherbe (2020) and reduces loan supply. Finally, if banks were fully equity financed ($\kappa^{\tau}_t = 1$ for all τ) and households did not value the liquidity services of deposits $\left(\frac{\pi_{t+1}}{1+r^D_t} = \Lambda_{t,t+1}\right)$, the loan pricing condition would merely contain the household's sdf and the loan payoff, $q^{\tau}_t = \mathbb{E}_t\left[\Lambda_{t,t+1}\mathcal{R}^{\tau}_{t+1}\right]$.

[9] Since the bank risk shock has a mean of one by assumption, we have $(1-G(\overline{\mu}_{t+1}) < 1)$.

Investment Good Firms. There is a representative producer for each of the three investment goods that intermediate firms acquire at price ψ_t^τ. To produce one unit of each investment good, these firms use $\left(1 + \frac{\Psi_I}{2}(\frac{i_t^\tau}{i_{t-1}^\tau})\right)$ units of the final good. The profit maximization problem

$$\max_{\{i_t^\tau\}_{t=0}^{\infty}} \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t \frac{c_t^{-\gamma_C}}{c_0^{-\gamma_C}} \left\{ \psi_t^\tau i_t^\tau - \left(1 + \frac{\Psi_I}{2} \left(\frac{i_t^\tau}{i_{t-1}^\tau} - 1 \right)^2 \right) i_t^\tau \right\} \right]$$

yields the first-order condition for (type-specific) investment good supply

$$\psi_t^\tau = 1 + \frac{\Psi_I}{2}\left(\frac{i_t^\tau}{i_{t-1}^\tau} - 1\right)^2 + \Psi_I\left(\frac{i_t^\tau}{i_{t-1}^\tau} - 1\right)\frac{i_t^\tau}{i_{t-1}^\tau} - \mathbb{E}_t\left[\Lambda_{t,t+1}\Psi_I\left(\frac{i_{t+1}^\tau}{i_t^\tau} - 1\right)\left(\frac{i_{t+1}^\tau}{i_t^\tau}\right)^2\right] . \quad (7)$$

Intermediate Good Firms. Having described the supply side of investment goods and loans, we now describe the demand side, which consists of three types of intermediate good firms. As customary in the literature, we do not allow for technology choices within firms. All three firm types produce intermediate goods z_t^τ, $\tau \in \{c, f, n\}$. The non-energy good is denoted by z_t^n, while the energy good is produced by two representative energy firms, clean and fossil. Firms maximize the present value of dividends, discounted by the firm managers' stochastic discount factor $\widetilde{\Lambda}_{t,t+1} \equiv \widetilde{\beta}\frac{c_{t+1}^{-\gamma_C}}{c_t^{-\gamma_C}}$ with $\widetilde{\beta} < \beta$. In the main text, we only present the problem of the fossil energy firm and report the first-order conditions of clean energy and non-energy firms in Appendix A. The production technology is linear in capital and subject to an uninsurable idiosyncratic productivity shock, giving rise to corporate default. As it is standard in the literature, we assume that the shock is i.i.d. log-normally distributed with standard deviation ς_M. We normalize its mean to $-\varsigma_M^2/2$, which ensures that the shock has a mean of one.

To finance their investment, firms can either use equity (negative dividends) or long-term loans l_t^τ of which a share $0 < \chi \leq 1$ matures each period. The non-maturing share $(1 - \chi)$ is rolled over at the loan price q_t^τ. Firms default on the maturing share χl_t^f, if revenues from production $p_t^f m_t z_t^f$ fall below the required loan repayment χl_t^f. In this case, banks are entitled to the period t output, but have to pay a restructuring costs φl_t^f. As outlined in Gomes et al. (2016), we assume that firms are restructured immediately which, together with the i.i.d. nature of idiosyncratic productivity shocks, permits aggregation into a representative fossil energy firm (see also Giovanardi et al., 2022).

Fossil energy firms are subject to emission taxes τ_t. We follow Heutel (2012) in assuming that unabated emissions are proportional to production, but we allow for of costly abatement η_t. Total emissions are therefore given by $e_t = (1 - \eta_t) z_t^f$ while the total emission tax payed in period t is given by $\tau_t(1-\eta_t)z_t^f$. Abatement costs are specified as

$$\Theta(\eta_t, z_t^f) = \frac{\theta_1}{\theta_2+1}\eta_t^{\theta_2+1} z_t^f \ , \tag{8}$$

with θ_1, $\theta_2 > 0$. They are proportional to output, such that the optimal abatement effort is given by

$$\eta_t^* = \left(\frac{\tau_t}{\theta_1}\right)^{\frac{1}{\theta_2}} \ . \tag{9}$$

Combing these elements, we can write dividends as

$$div_t^f = \mathbb{1}\{m_t > \overline{m}_t^f\} \cdot \left(p_t^f z_t^f - \tau_t(1-\eta_t)z_t^f - \frac{\theta_1}{\theta_2+1}\eta_t^{\theta_2+1} z_t^f - \chi \cdot \frac{l_t^f}{\pi_t}\right) - \\ - \psi_t^f i_t^f + q_t^f \left(l_{t+1}^f - (1-\chi)\frac{l_t^f}{\pi_t}\right) .$$

As in Giovanardi et al. (2022), we can reduce the firm maximization problem to a two-period consideration, after plugging in the capital accumulation constraint $i_t^f = k_{t+1}^f - (1-\delta_K)k_t$

$$\max_{k_{t+1}^f, l_{t+1}^f, \overline{m}_{t+1}^f} - \psi_t^f k_{t+1}^f + q_t^f \left(l_{t+1}^f - (1-\chi)\frac{l_t^f}{\pi_t}\right) + \mathbb{E}_t\Bigg[\widetilde{\Lambda}_{t+1} \cdot \Bigg\{\int_{\overline{m}_{t+1}^\tau}^\infty (p_{t+1}^\tau - \xi_{t+1}) \cdot m_{t+1} \cdot k_{t+1}^\tau - \\ - \chi \cdot \frac{l_{t+1}^\tau}{\pi_{t+1}} dF(m_{t+1}) + \psi_{t+1}^f (1-\delta_K) k_{t+1}^f + q_{t+1}^\tau \Big(l_{t+2}^\tau - (1-\chi)\frac{l_{t+1}^\tau}{\pi_{t+1}}\Big)\Bigg\}\Bigg] ,$$

subject to the default threshold $\overline{m}_{t+1}^f \equiv \frac{\chi l_{t+1}^f}{\pi_{t+1}(p_{t+1}^f - \xi_{t+1})k_{t+1}^f}$ and subject to the financing conditions given by banks' loan pricing condition (6). The carbon tax *compliance cost* per unit are obtained from plugging-in the optimal abatement effort η_t^* and summarizes all expenses induced by carbon taxation and abatement:

$$\xi_{t+1} \equiv \tau_t \left(1 - \left(\frac{\tau_t}{\theta_1}\right)^{\frac{1}{\theta_2}}\right) + \frac{\theta_1}{\theta_2+1}\left(\frac{\tau_t}{\theta_1}\right)^{\frac{\theta_2+1}{\theta_2}} \ . \tag{10}$$

Compliance costs are increasing in τ_t if $\theta_2 > 0$. All else equal, compliance costs increase the riskiness of fossil energy firms since they increase the break-even productivity shock realization above which the firm does not default. Firms take this into account when making their investment and leverage choices. The expected profitability of a defaulting firm is denoted by $G(\overline{m}_t^\tau) \equiv \int_0^{\overline{m}_t^\tau} m dF(m)$ and the default probability by $F(\overline{m}_t^\tau) \equiv \int_0^{\overline{m}_t^\tau} dF(m)$.

Loan and Bond Payoffs. Firms take the effect of their risk choice on loan prices into account when making their loan and investment decisions. The risk choice is linked to the loan price through the payoff $\mathcal{R}_t^\tau$, which we will describe now. The realized nominal payoff from investing in a unit of corporate loans is given by

$$\mathcal{R}_t^\tau = \chi \left(\frac{G(\overline{m}_t^\tau)}{\overline{m}_t^\tau} + 1 - F(\overline{m}_t^\tau) \right) - F(\overline{m}_t^\tau)\varphi + (1-\chi) q_t^\tau \pi_t \ , \quad \tau \in \{c, f, n\} \ . \tag{11}$$

The first term reflects the payoff from the share χ of maturing bonds: it consists of the production revenues banks seize in case of default and the repayment of the principal in case of no default. The term $F(\overline{m}_{\tau,t})\varphi$ are restructuring costs, while the rollover share $(1-\chi)$ of loans outstanding is valued at market price q_t^τ.

Firm Loan and Investment Choice. The first-order conditions for investment and loan issuance are given by

$$\frac{\partial q(\overline{m}_{t+1}^f)}{\partial l_{t+1}^f} \left(l_{t+1}^f - (1-\chi) \frac{l_t^f}{\pi_t} \right) + q(\overline{m}_{t+1}^f) = \mathbb{E}_t \left[\frac{\widetilde{\Lambda}_{t+1}}{\pi_{t+1}} \Big(\chi (1 - F(\overline{m}_{t+1}^f)) + (1-\chi) q(\overline{m}_{t+2}^f) \Big) \right] , \tag{12}$$

and

$$\psi_t^\tau = \frac{\partial q(\overline{m}_{t+1}^f)}{\partial k_{t+1}^f} \left(l_{t+1}^f - (1-\chi) \frac{l_t^f}{\pi_t} \right) + \mathbb{E}_t \left[\widetilde{\Lambda}_{t+1} \Big(\psi_{t+1}^\tau (1-\delta_K) + (p_{t+1}^f - \xi_{t+1}) \big(1 - G(\overline{m}_{t+1}^f) \big) \Big) \right] . \tag{13}$$

The first order condition (12) equates the marginal benefit of taking up a loan, net of a debt dilution term, with its costs. The costs consist of the redemption share χ, weighted by the repayment probability, and the roll-over part $(1-\chi)$, valued by the continuation value $q(\overline{m}_{t+2}^f)$. Equation (13) requires that the cost of investment (normalized to one) equals its expected discounted payoff, which consists of the value of undepreciated capital next period as well as the expected productivity conditional on repayment weighted by the fossil energy price net of taxes and abatement. By changing capital requirements κ_t^τ, bank regulation affects loan prices via the banker sdf $\overline{\Lambda}_{t+1}$, which enter both first-order conditions through $\frac{\partial q(\overline{m}_{t+1}^f)}{\partial l_{t+1}^f}$ and $\frac{\partial q(\overline{m}_{t+1}^f)}{\partial k_{t+1}^f}$. Analytical details on these expressions are provided in Appendix A. The role of firm-level default risk and loan supply is conceptually similar to Giovanardi et al. (2022), who study green-tilted collateral policy that has a similar transmission mechanism to the real sector. We refer to this paper for a detailed discussion of the implications for firm behavior.

Final Good Firms. Monopolistically competitive firms aggregate both energy inputs and the non-energy intermediate good together with labor into the final good y_t according to a nested CES-structure (see also Fried et al., 2021):

$$y_t = (1 - \mathcal{D}(\mathcal{E}_t))A_t \widetilde{z}_t^{\alpha} n_t^{1-\alpha} \ , \tag{14}$$

with

$$\widetilde{z}_t = \left(\widetilde{\nu}(z_t^e)^{\frac{\widetilde{\epsilon}-1}{\widetilde{\epsilon}}} + (1-\widetilde{\nu})(z_t^n)^{\frac{\widetilde{\epsilon}-1}{\widetilde{\epsilon}}}\right)^{\frac{\widetilde{\epsilon}}{\widetilde{\epsilon}-1}} \ , \tag{15}$$

where $\widetilde{\nu}$ is the weight on energy in the intermediate goods bundle and $\widetilde{\epsilon}$ is the elasticity between energy and non-energy goods. The energy bundle is, in turn, given by

$$z_t^e \equiv \left(\nu(z_t^c)^{\frac{\epsilon-1}{\epsilon}} + (1-\nu)(z_t^f)^{\frac{\epsilon-1}{\epsilon}}\right)^{\frac{\epsilon}{\epsilon-1}} \ , \tag{16}$$

where ν is the clean energy weight in the energy bundle. Total factor productivity A_t follows an AR(1)-process in logs with persistence ρ_A and standard deviation σ_A. Final good firms sell their differentiated good with a markup over their marginal costs, subject to quadratic price adjustment cost, proportional to the nominal value of sales:

$$ac_t(i) = \frac{\Psi_P}{2}\left(\frac{P_t(i)}{P_{t-1}(i)} - 1\right)^2 P_t y_t \ . \tag{17}$$

The cost minimization problem yields the following standard first-order conditions

$$mc_t \alpha \widetilde{\nu} \nu \frac{y_t}{\widetilde{z}_t}\left(\frac{\widetilde{z}_t}{z_t^e}\right)^{\frac{1}{\widetilde{\epsilon}}}\left(\frac{z_t^e}{z_t^c}\right)^{\frac{1}{\epsilon}} = p_t^c \ , \tag{18}$$

$$mc_t \alpha \widetilde{\nu}(1-\nu) \frac{y_t}{\widetilde{z}_t}\left(\frac{\widetilde{z}_t}{z_t^e}\right)^{\frac{1}{\widetilde{\epsilon}}}\left(\frac{z_t^e}{z_t^f}\right)^{\frac{1}{\epsilon}} = p_t^f \ , \tag{19}$$

$$mc_t \alpha (1-\widetilde{\nu}) \frac{y_t}{\widetilde{z}_t}\left(\frac{\widetilde{z}_t}{z_t^n}\right)^{\frac{1}{\widetilde{\epsilon}}} = p_t^n \ , \tag{20}$$

$$mc_t (1-\alpha)\frac{y_t}{n_t} = w_t \ , \tag{21}$$

where mc_t is the real marginal cost of production for the final good.

Denoting with ϕ the elasticity of substitution across final goods, final good monopolists face price rigidities à la Rotemberg, with Ψ_P being the parameter governing the degree of nominal rigidity. The price-setting maximization problem of final good producer i is then given by

$$\max_{\{P_t(i)\}_{t=0}^{\infty}} \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t \frac{c_t^{-\gamma_C}}{c_0^{-\gamma_C}} \left\{ \left(\frac{P_t(i)}{P_t} \right)^{-\phi} \left(\frac{P_t(i)}{P_t} - mc_t \right) y_t - \frac{\Psi_P}{2} \left(\frac{P_t(i)}{P_{t-1}(i)} \right)^{-\phi} \left(\frac{P_t(i)}{P_t} - 1 \right)^2 y_t \right\} \right] .$$

Solving the maximization problem and imposing symmetry, we arrive at the standard New Keynesian Philips curve

$$\mathbb{E}_t \left[\Lambda_{t,t+1} \frac{y_{t+1}}{y_t} \left(\pi_{t+1} - 1 \right) \pi_{t+1} \right] + \frac{\phi}{\Psi_P} \left(\mathrm{mc}_t - \frac{\phi - 1}{\phi} \right) = \left(\pi_t - 1 \right) \pi_t .$$

Public Sector. Government bonds are supplied inelastically. Note that government bonds are risk-free, such that their nominal payoff is given by $\mathcal{R}_t^b = \chi + (1-\chi) q_t^b$. The price of government bonds thus solely reflects the banker sdf and the benefits of deposit financing. The government bond yield is, therefore, distinct from the deposit rate and can be lower (for example, if the equity requirement is very small, ceteris paribus) or higher (for example, if bank default risk is very large, ceteris paribus). The model is closed by assuming that the central bank sets the nominal interest rate according to a Taylor-type rule:

$$1 + r_t = (1 + r^{SS}) \pi_t^{\varphi_\pi} , \tag{22}$$

where r_t is defined through equation (3). We specify the policy rate in terms of an interest rate that is not traded in a market in our model. Thereby, we exclude interactions between the policy rate (and, thus, nominal rigidities) with deposit demand. In steady state, the real rate is simply pinned down by the household's time preference parameter β.

Pollution and Resource Constraint. The law of motion for the stock of atmospheric carbon $\mathcal{E}_t$ evolves according to $\mathcal{E}_t = \delta_E \mathcal{E}_{t-1} + e_t$ with $\delta_E < 1$. As in Giovanardi et al. (2022), the economic damage from emissions is represented by a fraction of GDP and specified as

$$\mathcal{D}(\mathcal{E}_t) = 1 - \exp(-d_E \mathcal{E}_t) . \tag{23}$$

The model is closed by assuming that carbon tax revenues and DIA losses are rebated in lump-sum fashion to households ($T_t = \tau_t e_t - T_t^{DIA}$). We follow Clerc et al. (2015) and Mendicino et al. (2018) in assuming that the DIA incurs direct efficiency losses $T_t^{DIA} = \zeta \cdot F(\overline{\mu}_t) \cdot d_t$ that are proportional to the amount of deposits under management by the DIA. The resource constraint is given by

$$y_t = c_t + \sum_{\tau\in\{c,f,n\}} i_t^\tau \Big(1 + \frac{\Psi_I}{2}\big(\frac{i_t^\tau}{i_{t-1}^\tau} - 1\big)^2\Big) + \frac{\Psi_P}{2}\big(\pi_t - 1\big)^2$$

$$+ \frac{\theta_1}{\theta_2+1}\left(\frac{\tau_t}{\theta_1}\right)^{\frac{\theta_2+1}{\theta_2}} z_t^f + \varphi \cdot F(\overline{m}_t) + \zeta \cdot F(\overline{\mu}_t) \cdot d_t \ , \tag{24}$$

where the abatement costs are evaluated at the optimal abatement effort η_t^*, given the tax rate τ_t. Note that the benefits of higher deposit supply do not enter the resource constraint, but are part of the welfare objective via the household utility function.

3 Calibration

Each period corresponds to one quarter. Most parameters take standard values used in E-DSGE models, while parameters governing financial frictions are set to match moments typically used in the macro banking literature. We describe the parameters associated with each group of agents in turn.

Households and Banks. We fix household's consumption CRRA parameter $\gamma_C = 2$ and steady state labor supply at $\overline{n} = 0.3$. The household discount factor β to 0.995, implying an annualized real interest rate of 2%. The deposit spread is defined as

$$s_t^{dep} \equiv (1 + r_t^{dep})^4 - (1 + r_t)^4 \ ,$$

where r_t is the interest rate implied by the household SDF Λ_{t+1} that does not take the utility benefits of deposits into account. If households value the liquidity services of bank deposits, the deposit spread s_t^{dep} is negative. We set the liquidity curvature parameter in household utility to $\gamma_D = 1.5$.[10] The weighting parameter $\omega_D = 0.095$ matches the deposit spread of -125bp used in Gerali et al. (2010). Government bond supply is fixed and implies a 100% debt-to-GDP ratio.

The standard deviation of banks' risk shock $\varsigma_\mu = 0.0275$ implies an annualized bank failure rate of 0.7% matching the data moment used in Mendicino et al. (2020).[11] We set the deadweight loss parameter of the deposit insurance agency to $\zeta = 0.017$, which renders a long run capital requirement of 8% optimal from a utilitarian welfare perspective, holding the carbon tax at zero. In other words, we assume that the current symmetric capital requirements required by the Basel framework is optimal.

[10]We provide a sensitivity analysis of our key results with respect to the curvature parameter.

[11]We provide a robustness analysis of our main policy experiments targeting an annualized failure rate of 2%, which is for example used by Clerc et al. (2015).

In the symmetric case, bank capital regulation is governed by a single parameter $\kappa_t^{sym} \equiv \kappa_t^b = \kappa_t^c = \kappa_t^f = \kappa_t^n$ that also applies to government bond holdings. In practice, bank capital regulation is specified along multiple dimensions. Equity requirements depend on risk-weighted assets. By setting risk-weights, the regulator can effectively specify sector-specific capital requirements. In addition, bank equity is also subject to a leverage ratio that depends on the market value of assets. Due to the macro approach of our model, we can not finely distinguish between equity and leverage regulation. Specifically, the bank risk shock applies to all bank assets and even a bank that solely invests deposits into government bonds is risky in our model. This is inconsistent with a narrow interpretation of κ_t^{sym} as equity regulation, which typically sets risk-weights on government bonds to zero. Taken together, capital requirements have attributes of both types of regulation, while sector-specific regulation is best interpreted as differentiated risk-weights.

Intermediate Good Firms. The quarterly capital depreciation rate is fixed at the standard value of $\delta_K = 0.025$. In the symmetric baseline calibration ($\kappa_t^b = \kappa_t^c = \kappa_t^f = \kappa_t^n = \kappa^{sym}$), we impose identical financial frictions for all intermediate good firms. Following the calibration strategy in Giovanardi et al. (2022), we fix the average bond maturity to five years ($\chi = 0.05$) and jointly calibrate firm owners' discount factor $\widetilde{\beta} = 0.989$, the standard deviation of idiosyncratic productivity shocks $\varsigma_M = 0.17$ and the restructuring cost parameter $\varphi = 0.75$ to match the observed time-series average of corporate leverage (40% at market values), the corporate default rate of 2.7% and a loan spread of 124bp, the latter both following recent work by Mendicino et al. (2020) and Mendicino et al. (2021).[12] The spread is in the typical range of values used in the literature: Giovanardi et al. (2022) target a value of 100bp, while Mendicino et al. (2018) use a value of 108bp. The market value of leverage is defined as $lev_t^\tau = \frac{q_t^\tau b_{t+1}^\tau}{\psi_t^\tau k_{t+1}^\tau}$. Loan spreads can be directly obtained from prices:

$$s_t^\tau \equiv \left(1 + \frac{\chi}{q(\overline{m}_{t+1}^\tau)} - \chi\right)^4 - (1 + r_t)^4 \, .$$

Investment and Final Good Producers. We calibrate parameters governing nominal rigidities (final good CES $\phi = 3.8$ and price adjustment cost $\Psi_P = 71.5$) and the monetary policy response (φ_π) based on values reported in the ECB's New Area Wide Model II (Coenen et al., 2019). The investment adjustment cost $\Psi_I = 10$ are consistent with the E-DSGE literature (see Annicchiarico et al. (2022) and the references therein) and medium scale DSGE models, such as the ECB's area wide model (see Coenen et al. (2019)

[12]Elenev et al. (2021) target a higher value of loan delinquencies of almost 4% p.a., which is based on US data. Recalibrating the model to match a higher corporate default frequency does not materially change our results.

and the references therein). The Cobb-Douglas coefficient is fixed at $\alpha = 1/3$. Persistence and standard deviation of the aggregate TFP shock are set to $\rho_A = 0.95$ and $\sigma_A = 0.005$, which are standard values in the business cycle literature.

The sectoral shares and substitution elasticities crucially determine the effects of carbon taxes and of differentiated capital requirements. In our model, these shares are determined by the weighting parameters $\widetilde{\nu}$ and ν in equation (15) and equation (16), respectively. The elasticity $\widetilde{\epsilon} = 0.2$ between energy and non-energy goods follows Bartocci et al. (2022) who calibrate a medium scale DSGE model to sectoral data from the EU. The weighting parameter $\widetilde{\nu} = 0.0015$ then implies an energy share of 10% in the final good production, which is also used as a calibration target in Bartocci et al. (2022). We set $\nu = 0.3865$ to target a clean energy sector size of 20%. As in Fried et al. (2021), we fix the elasticity between clean and fossil energy at $\epsilon = 3$.

Emissions and Pollution Damage. The calibration of the model's climate block largely follows Carattini et al. (2021): the emission decay parameter is given by $\delta_E = 0.9979$ while the weighting and curvature parameters of abatement costs are set to $\theta_1 = 0.0335$ and $\theta_2 = 1.6$. This implies that full abatement for any carbon tax exceeding 126\$/ToC, which is in line with the value used in Ferrari and Nispi Landi (2022). The parameter d_E=7E-05 governing climate change damages implies a long-run loss of 5.2% relative to GDP (Carattini et al., 2021). The parameterization is summarized in Table 1.

Model Fit. Table 2 presents the model fit. The second moments in the lower panel are collected from recent macro-finance and macro-banking literature and are largely based on real, linearly de-trended variables. The pro-cyclicality of emissions is based on US data (Khan et al., 2019) and is captured well by the model.

Optimal Symmetric Capital Requirements. Before discussing preferential capital requirements, we demonstrate the key trade-off shaping optimal capital requirements in our model. Figure 1 shows how a change in the symmetric capital requirement κ^{sym} affects welfare and macroeconomic aggregates. The top right panel demonstrates that tighter requirements reduce the failure probability of banks. Since the pdf $f(\overline{\mu}_{t+1})$ of the bank risk shock is increasing in the relevant region of $\overline{\mu}_{t+1}$, the marginal effect of a higher κ^{sym} on $F(\overline{\mu}_{t+1})$ declines in $\overline{\mu}_{t+1}$. Similarly, the deposit spread becomes more negative for higher capital requirements since deposits become scarcer and, thus, more valuable to households (bottom left panel).

In the bottom right panel, we show how changes to the capital requirement affect risk-taking behavior by the non-financial sector. For low capital requirements, a tightening reduces risk-taking by the non-financial sector, since banks' loan pricing condition (6)

Table 1: Baseline Calibration

Parameter	**Value**	**Source/Target**
Households		
Household discount factor β	0.995	Standard
Consumption CRRA γ_C	2	Standard
Liquidity curvature γ_D	1.5	In line with Begenau (2020)
Liquidity weight ω_D	0.095	Deposit spread
Labor supply $\overline{n}$	0.3	Standard
Technology		
Price adjustment parameter Ψ_P	71.5	Coenen et al. (2019)
Final good CES ϕ	3.8	Coenen et al. (2019)
Investment adjustment parameter Ψ_I	10	Standard
Capital depreciation rate δ_K	0.025	Standard
Cobb-Douglas coefficient α	1/3	Standard
Energy weight $\widetilde{\nu}$	0.0015	Energy share
Energy/non-energy CES $\widetilde{\epsilon}$	0.2	Bartocci et al. (2022)
Clean weight ν	0.3865	Clean energy share
Fossil/clean CES ϵ	3	Fried et al. (2021)
Climate Block		
Damage parameter d_E	7e-05	Pollution damage/GDP
Abatement cost parameter θ_1	0.0265	In line with Coenen et al. (2023)
Abatement cost parameter θ_2	1.6	Heutel (2012)
Pollution decay δ_E	0.9979	Heutel (2012)
Financial Markets		
Firm-owner discount factor $\widetilde{\beta}$	0.989	Leverage ratio
Standard deviation bank risk ς_μ	0.0275	Bank failure rate
Standard deviation firm risk ς_M	0.17	Firm default rate
Bond maturity parameter χ	0.05	Giovanardi et al. (2022)
Restructuring costs φ	0.75	Loan spread
Deposit insurance loss ζ	0.017	Optimality of κ^{sym}
Government bond supply	2.52	Debt-to-GDP ratio%
Capital requirement κ^{sym}	0.08	Basel III
Monetary policy response φ_π	2.75	Coenen et al. (2019)
Shocks		
Persistence TFP ρ_A	0.95	Standard
TFP shock standard deviation σ_A	0.005	Standard

shifts downward. For sufficiently high capital requirements, the marginal effect reverts: a higher κ^{sym} still forces banks to reduce deposit supply, which become increasingly scarce. This increases the term $\frac{1}{1+r_t^D} - \Lambda_{t+1}$ in banks' loan pricing condition. Since the additional reduction bank failure probability becomes small and household's valuation of deposits exhibits a sufficiently large curvature, this increases loan supply. This effect is also present

Table 2: Model Fit

Moment	Model	Data	Source
Means			
Deposit Spread	-128bp	-125bp	Gerali et al. (2010)
Loan Spread	122bp	125bp	Mendicino et al. (2021)
Firm Leverage (%)	40	40	Gomes et al. (2016)
Firm Default Rate (%)	2.7	2.7	Mendicino et al. (2021)
Bank Failure Rate (%)	0.7	0.7	Mendicino et al. (2021)
Dynamics			
Emissions-GDP $cor(y, e)$	0.76	0.64	Khan et al. (2019)
Relative vol. consumption $\sigma(c)/\sigma(y)$	0.93	0.85	Coenen et al. (2019)
Relative vol. investment $\sigma(i)/\sigma(y)$	2.00	2.53	Coenen et al. (2019)
Loan spread vol. $\sigma(s)$	67bp	68bp	Mendicino et al. (2021)
Debt $cor(y, l)$	0.71	0.65	Jungherr and Schott (2022)
Firm default-GDP $cor(y, F(\overline{m}))$	-0.69	-0.55	Kuehn and Schmid (2014)
Bank def.-firm def. $cor(F(\overline{\mu}), F(\overline{m}))$	0.30	0.64	Mendicino et al. (2021)

in Begenau (2020).

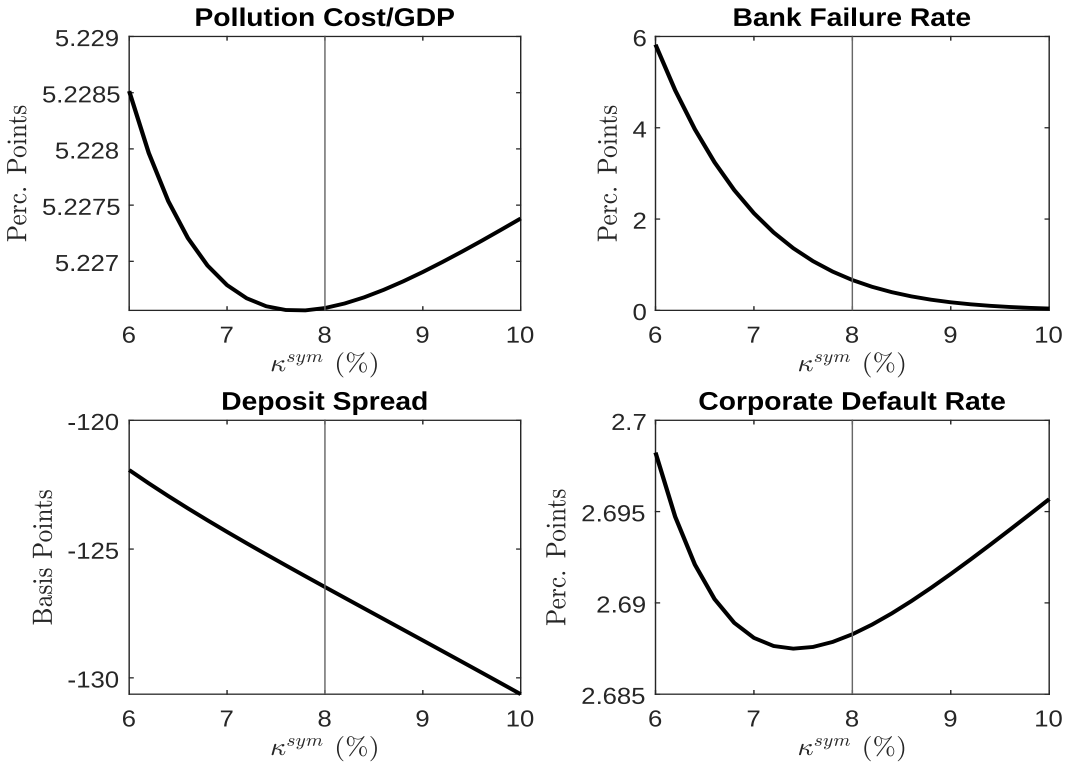
4 Bank Regulation as Climate Policy Instrument

In this section, we use our calibrated model to study the positive and normative implications of differentiated capital requirements as climate policy instrument. The analysis focuses on time series means and is based on a second order approximation of policy functions and welfare around the deterministic steady state. Since our model does not feature technological change, we interpret our results as *medium-run*, with a time horizon of around 25 years.

Specifically, we vary κ^f while keeping $(\kappa^b, \kappa^c, \kappa^n)$ at their baseline value of 8%. Fossil loans become more expensive for banks to hold, since they have to be refinanced by more costly equity issuance. For a 100% capital requirement on fossil loans, the respective loan spreads increases to around 170bp, which is substantial given the baseline value of 121bp (see the upper left panel of Figure 2). Since debt financing becomes relatively more expensive for fossil firms, their leverage declines by around one percentage point. Formally, by the first-order condition for leverage (12), the optimal $\overline{m}^c_{t+1}$ declines if the loan pricing schedule shifts downwards (see equation (6) and Giovanardi et al. (2022) for a detailed discussion). This also implies a decline in medium-run fossil default rates. At the same time, their real investment declines by 1.5%, since overall financing costs are more expensive.

This drop of fossil investment induces a moderate decline in carbon emissions (bottom left panel), which increases welfare. However, there are two additional welfare-relevant

Figure 1: Macroeconomic Effects of Symmetric Capital Requirements



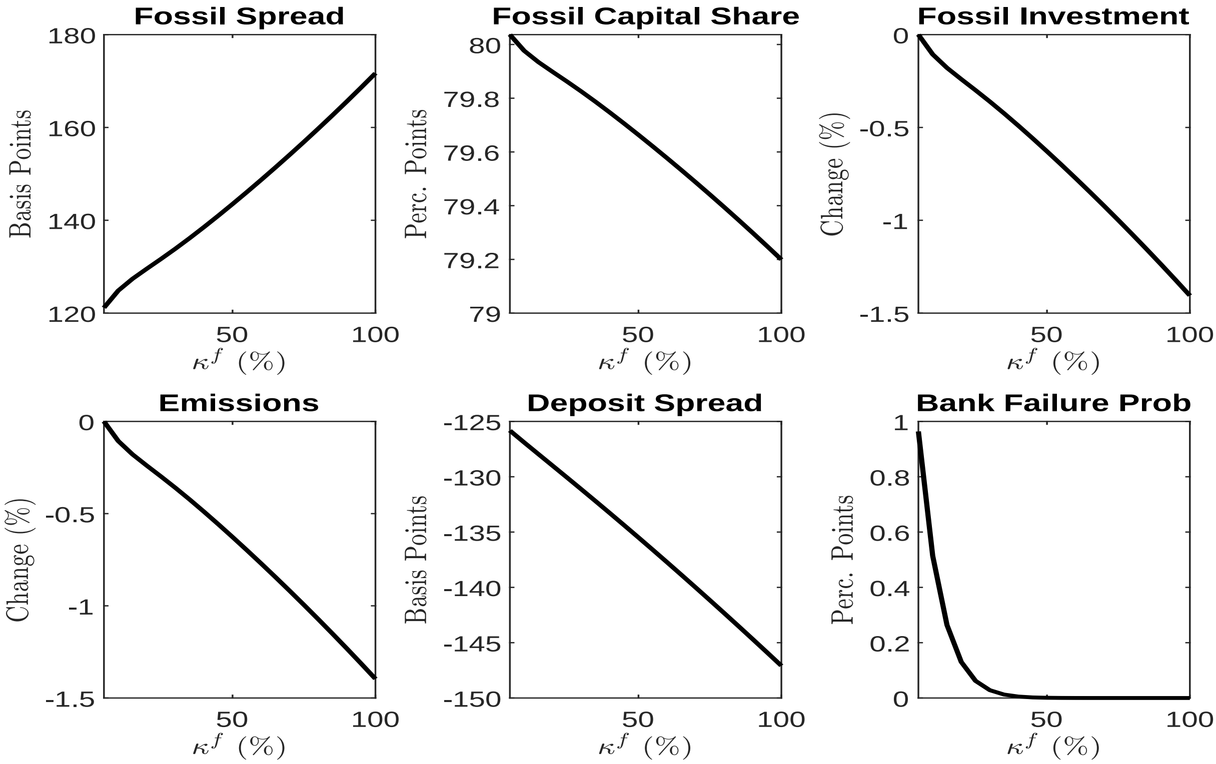
Notes: Welfare changes are expressed in consumption equivalents and are, like default costs, expressed relative to the baseline calibration. Bank failure probability and deposit spread are annualized.

effects of such a policy: first, higher capital requirements make banks less risky, as the bank failure probability in the bottom right panel shows. At the same time, more stringent capital requirements require banks to downsize their balance sheet, which makes deposits scarcer (bottom middle panel). The net effect on welfare, thus, depends on the magnitude of each effect.

Table 3 summarize the macroeconomic implications of a 100% capital requirement on fossil loans and provides a benchmark against a very modest carbon tax. As the second column of Table 3 shows, the effect on the fossil capital share (within the energy sector) are relevant at a macroeconomic level: it declines from 80% to around 79%. Since issuing loans becomes more costly for fossil firms, the fossil loan share declines by more than the fossil capital share. Consequently, the fossil leverage ratio declines. Due to an equilibrium effect operating through deposit scarcity and bank loan supply, clean firms increase their leverage ratio which ultimately translates into higher medium-run default rates in the clean energy sector. The substantial scarcity of deposits, indicated by the deposit spread of -145bp, implies that this policy reduces welfare by 0.19% in consumption equivalents.

It is instructive to compare the climate effects of differentiated capital requirements to carbon taxes. Since capital requirements also have strong effects on financial markets and

Figure 2: Medium-Run Effects of Fossil Penalizing Capital Requirements



Notes: The relative change of fossil investment and emissions is expressed relative to the baseline $\kappa^{sym} = 8\%$.

can easily be welfare-reducing, we evaluate their climate impact in isolation from other welfare relevant dimensions. The fourth and fifth column of Table 3 presents two different ways of mapping capital requirements into carbon taxes. Implementing a carbon tax of 3.05$ per tonne of carbon (ToC) yields the same fossil capital share (79.22%) that obtains also from a 100% equity requirement for fossil loans.[13] Notably, the emission reduction is much larger for the tax (-10.58% compared to -1.32%). The reason for this stark difference is that capital requirements do not affect firms' incentive to abate emissions. Instead, size and capital holdings of fossil energy firms decline, but the emission of fossil firms intensity remains unchanged.

We also compare these results to a carbon tax of 0.13$/ToC, which is arguably a rather symbolic tax. However, as the last column of Table 3 shows, even this symbolic tax already has the same climate impact of a strong fossil penalizing capital requirements:

[13]The model-implied carbon tax is converted into $/ToC following Carattini et al. (2021): we convert model units of output ($y^{model} = 0.57535$ in the baseline calibration) to world GDP ($y^{world} = 105.000$ billion USD in 2022, at PPP, see IMF, 2022) since we abstract from rest of the world emissions. We furthermore convert model emissions ($e^{model} = 0.9761$ in the baseline calibration) into world emissions ($e^{world} = 33$ gigatonnes in 2022.). The model-implied carbon price is given by $p^{\text{carbon}} = \frac{y^{\text{world}}/y^{\text{model}}}{e^{\text{world}}/e^{\text{model}}}\tau$ $/ToC.

Table 3: Medium-Run Effects of Selected Policies

Moment	Baseline	$\kappa^f = 1$	3.05$ tax	0.13$ tax
Clean Spread	124bp	116bp	123bp	124bp
Fossil Spread	124bp	172bp	123bp	124bp
Clean Leverage	40.0%	40.1%	40.0%	40.0%
Fossil Leverage	40.0%	38.8%	40.0%	40.0%
Clean Default	2.7%	2.8%	2.7%	2.7%
Fossil Default	2.7%	1.9%	2.7%	2.7%
Fossil Capital Share	80.00%	79.20%	79.20%	79.96%
Δ GHG Stock	-	-1.33%	-10.58%	-1.33%
Damage/GDP	5.23%	5.16%	4.69%	5.16%
Bank Failure Prob	0.7%	0%	0.7%	0.7%
Deposit Spread	-126bp	-147bp	-126bp	-136bp
Δ Welfare	-	-0.19%	+1.56%	+0.21%

emissions decline by around 1.33% relative to the baseline. At the same time, this policy does not have an affect on leverage and default probabilities in the non-financial sector. This essentially rules out capital requirements as a suitable climate policy instrument.

5 Bank Regulation and Climate Policy

In the previous sections, we have shown that differentiated bank regulation has a negligible effect on emissions. In this section, we take the complementary approach and study how optimal bank regulation is affected by a more suitable climate policy instrument: carbon taxes. We proceed in two steps. First we show the optimal medium-run response of bank capital regulation to carbon taxes.[14] In a second step, we explicitly introduce climate policy uncertainty in the form of carbon tax shocks, which can be interpreted as sudden shifts in the political ability to implement taxes. This could simply be the election of an environmental-friendly party. Alternatively, one could think of events that make climate change and its costs more salient and, thus, motivate incumbent policymakers to suddenly tighten climate policy.

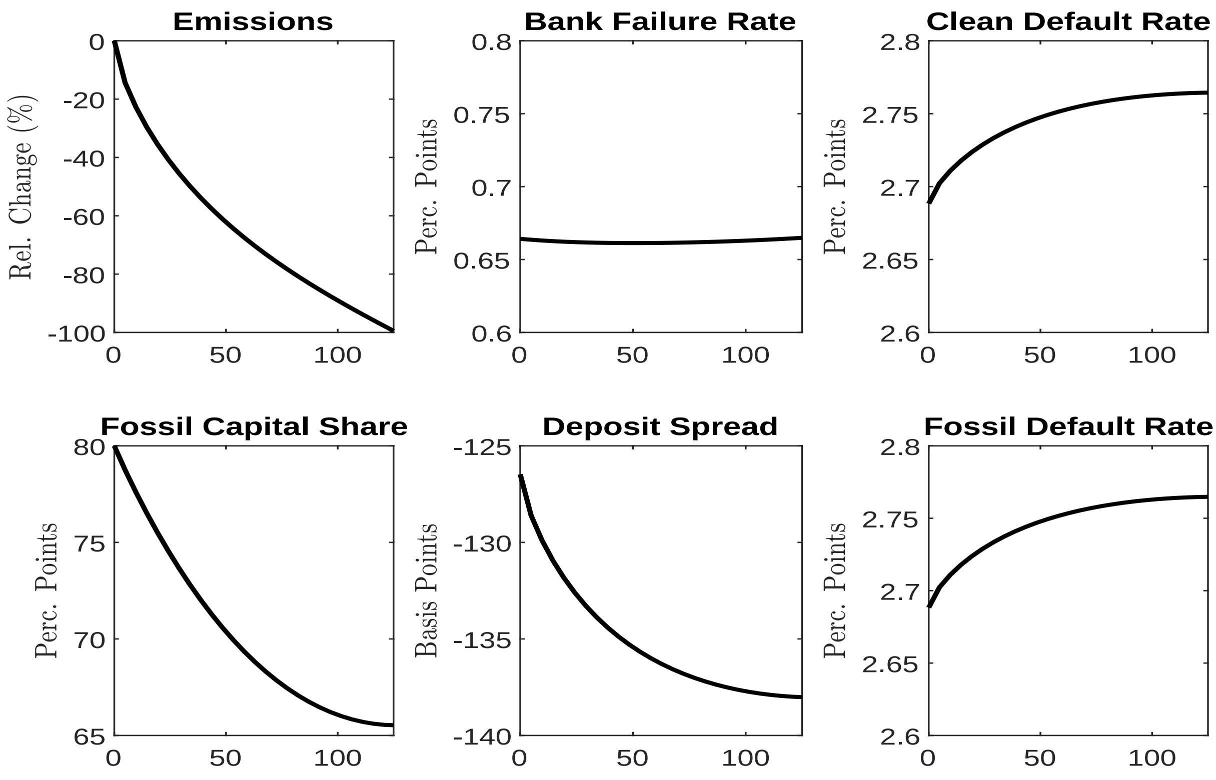
[14] Throughout the analysis, we focus on the interactions of climate policy and bank regulation and abstract from physical risk. Since all parameters governing the production sector are time-invariant in our model, i.e. there is no technical change, the model is not necessarily suited to study physical risk which likely materializes over a longer horizon. We nevertheless emphasize that it is possible to re-interpret our multi-sector structure as firms that are more and less susceptible to physical risk.

5.1 Bank Regulation and Anticipated Climate Policy

As in Ferrari and Nispi Landi (2022) or Coenen et al. (2023), we focus on taxes consistent with net zero emissions. In our model, this corresponds to full abatement ($\eta_t^* = 1$) and obtains under carbon prices larger than $p_t^{\text{carbon}} = 125\$/\text{ToC}$, which is a typical value in E-DSGE models. Under full abatement, the fossil capital share declines to 65 percentage points. Since our model does not feature technological change, i.e. the elasticity and weighting coefficients in (16) and (15) are fixed, costly abatement is the only way to achieve net zero. This is a reasonable benchmark policy in the medium run, while we would expect policies inducing a full shift towards clean energy to be optimal in the long run.

The macroeconomic effects of a permanent carbon tax and its implications for bank capital regulation are summarized in Figure 3. The top row shows that the decline of emissions due to carbon taxes is strongest for small taxes. This follows from the convex specification of adaptation costs $\frac{\theta_1}{\theta_2+1}\eta_t^{\theta_2+1} z_t^f$. Similarly, the damage/GDP ratio and fossil capital share decline more slowly as carbon prices increase.

Figure 3: Medium-Run Effects of Carbon Taxes



Notes: The carbon tax is expressed in \$/ToC.

In this model, the bank capital requirement is always binding and, therefore, the bank failure rate does not depend on the carbon tax (middle row of Figure 3). However, the size of the aggregate bank balance sheet is negatively affected by carbon taxes: due to the imperfect substitutability of clean and fossil energy as well as energy and non-energy goods, the additional loan demand by clean and non-energy firms does not fully compensate the drop in fossil loan demand. To satisfy their regulatory equity requirement, banks reduce equity and deposits proportionally. Since the reduction of bank balance sheets implies a smaller supply of deposits to households, deposits are more valuable to households: the deposit spread widens by around 10bp, which reduces bank funding costs.

The scarcity of deposits in turn has a positive effect on loan supply: the deposit financing wedge in the loan pricing condition equation (6) widens such that loan rates decline ceteris paribus. The increase in loan supply associated with deposit scarcity is a well-studied feature in the literature on bank capital regulation (see Begenau, 2020 and the references therein). This mechanism is furthermore very similar to the adverse effects of stringent capital regulation on liquidity provision to households that we already discussed in Section 4.

To fully characterize the pass-through of carbon taxes to the real economy, the effects of higher loan supply for the financing decision of *all* non-financial firms has to be taken into account as well. Their first order condition (12) implies that firms increase their borrowing, investment, and default risk. This increases corporate default rates for all firms by almost 0.1 percentage points, which is non-negligible from a macroeconomic perspective given the baseline level of 2.7%. As the lower panel of Figure 3 reveals, the increase in corporate default rates is identical for clean and fossil energy firms. The reason behind this - at first glance puzzling - symmetry is that the first-order condition for loans (12) does not directly depend on the tax rate but only on their relative impatience (the reason firms borrow) and bank-specific frictions (the conditions at which they can borrow). Put differently, anticipated carbon taxes do not differentially affect the risk choice of firms since the financial friction in the banking sector enter credit supply symmetrically.

How do these macroeconomic effects shape optimal bank capital regulation in the medium-run? The bank failure rate and its macroeconomic costs via the deposit insurance agency are unaffected by carbon taxes since capital requirements are binding in all states. At the same time, deposit supply contracts and the default rate of non-financial firms increases symmetrically across sectors. Capital requirements should, therefore, be relaxed. We quantitatively re-evaluate the optimal capital requirement under the assumption that stringent carbon taxes are in place and find that a symmetric relaxation to $\kappa^{sym} = 7.9\%$ is optimal from a utilitarian welfare perspective. Notably, fiscal policy could mitigate this effect by expanding government bond supply. Since this model abstracts from further frictions in the conduct of fiscal policy, it is not necessarily well suited to make a normative statement which of these policies is better suited to address the tax-induced scarcity of liquid assets.

5.2 Bank Regulation and Climate Policy Surprises

Up to this point, we considered time-invariant policies aimed at emission reductions and only found modest sector-specific effects. In particular, even a stringent climate policy has no heterogeneous effects on default risk - provided carbon taxes are anticipated and the economy has sufficient time to adjust. Consequently, optimal bank regulation is symmetric as well. However, there is a case for differentiated *short-run* capital requirements in response to carbon tax *shocks*. Optimal bank regulation increases the capital requirement on clean loans while simultaneously reducing it for dirty loans. By leaning against carbon taxes, bank regulation reduces fluctuations associated with tax shocks that stem from firms' risk-taking decision and default risk. Importantly, the optimal differentiated response of capital requirements does not stem from time variation in the bank regulation trade-off between liquidity provision and risk-taking by banks vis-a-vis households. Instead, by changing sector-specific loan supply, differentiated capital requirements affect the risk-taking behavior of the corporate sector vis-a-vis banks.

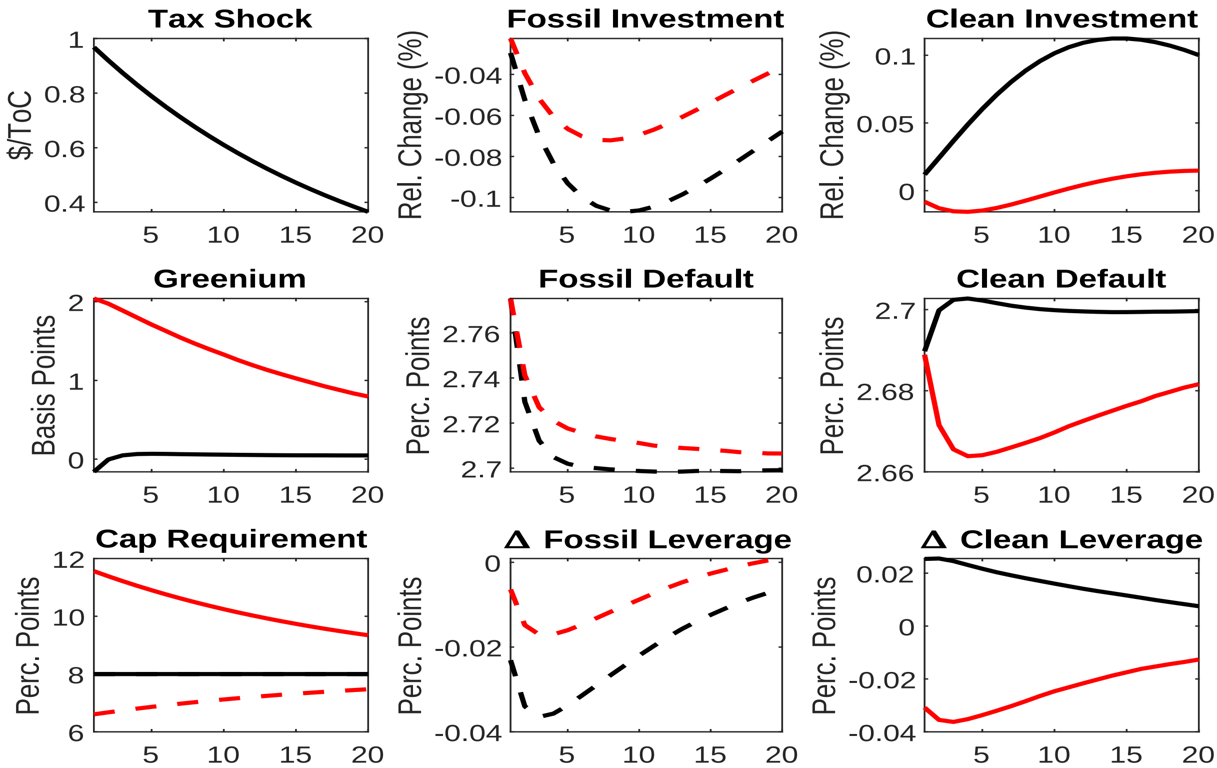
Carbon Tax Shocks. For the remainder of the section, we fix the level of the carbon tax at a medium-run level of $p_t^{\text{carbon}} = 50\$/\text{ToC}$ and consider shocks to carbon taxes. Specifically, carbon taxes follow an AR(1)-process,

$$\tau_t = (1 - \rho_\tau)\tau^{SS} + \rho_\tau \tau_{t-1} + \sigma_\tau \epsilon_t^\tau \ . \tag{25}$$

Its persistence is fixed at $\rho_\tau = 0.95$ and the shock variance σ_τ^2 is set such that a one standard deviation shock corresponds to an increase of 1\$/ToC, which corresponds to the size of carbon price shocks reported in Kaenzig (2023).

The black lines in Figure 4 display the sectoral effects of a surprise increase in carbon taxes. Since abatement is costly, compliance cost ξ_t pick up and have similar effects as a negative productivity shock to fossil firms. Fossil investment (dashed lines in the top panel) decreases on impact and reaches it trough after about 2 years. Likewise, clean investment increases by around 0.4%, with the peak being reached only after 3 years. Since fossil energy firms experience a sudden drop in their revenues, their default rate increases on impact from 2.7% to more than 2.8%, which is quantitatively relevant. It reverts to the steady state level relatively quickly. Again, the opposite effect can be observed for clean firms (lower panel of Figure 4). After the impact of the shock, clean firms engage in risk-taking. Their leverage remains above the pre-shock level for multiple periods. At the same time, fossil firms persistently de-leverage (bottom panel). This effect is consistent with results reported in Kacperczyk and Peydro (2022). The heterogeneous response of firm risk-taking is also reflected in the greenium (left middle panel of Figure 4), which is negative on impact and turns slightly positive after a few quarters.

Figure 4: Effect of Carbon Tax Shock: Sectors

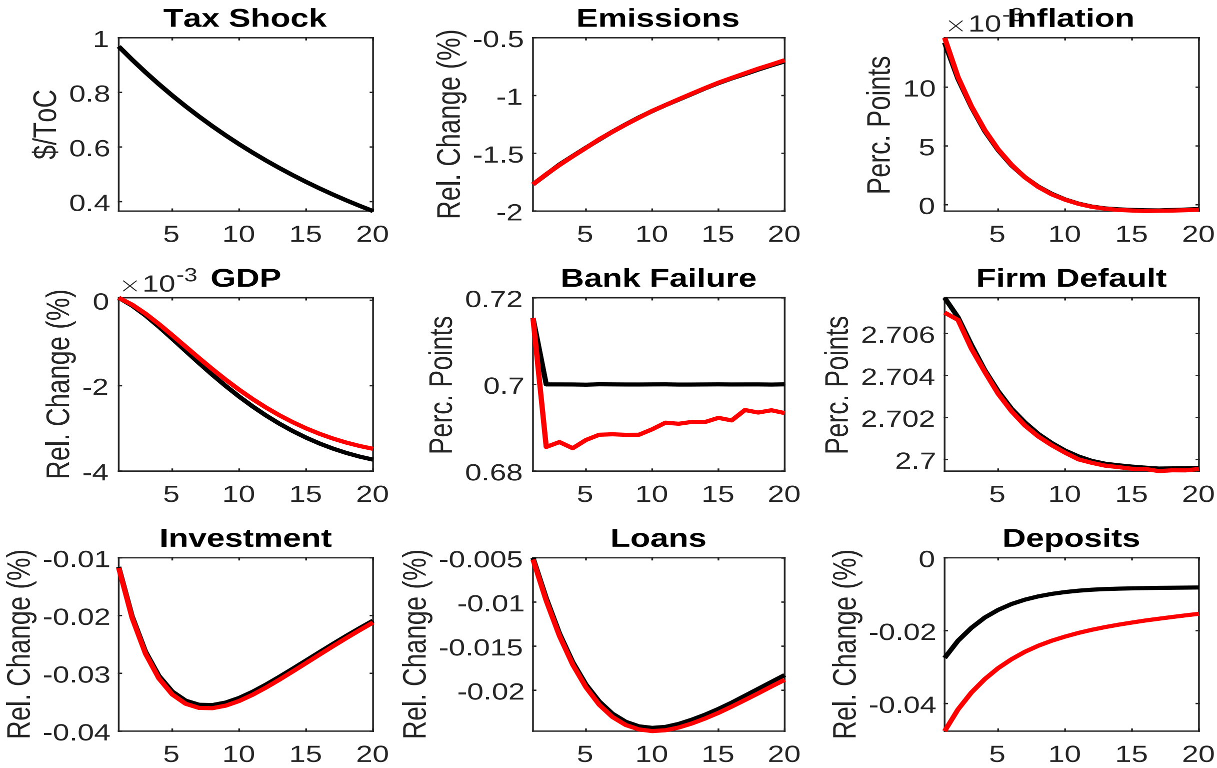


Notes: Impulse response to a 1$/ToC tax shock. Black represents the case of constant capital requirements. Red represents the optimal simple rule $\varphi_{\kappa}^{c} = 0.4$ and $\varphi_{\kappa}^{f} = -0.1$. The dashed lines refer to fossil energy producers.

In Figure 5, we turn to macroeconomic aggregates. The upper panel of Figure 5 shows that the tax shock generates a substantial decline in carbon emissions due to the temporarily high abatement incentives for fossil firms. The negative effects on fossil energy firms reduce energy supply ceteris paribus and drive up the energy price. As a by-product, this increases the inflation rate by around 0.02 percentage points, which is of a similar magnitude as the empirical results in Kaenzig (2023). Since both energy goods are imperfectly substitutable, clean energy firms can not fully compensate the productivity loss of fossil energy firms: aggregate energy supply and, thus, economic activity as measured by GDP and real investment contracts. Tax shocks are recessionary and resemble a negative shock to TFP, as shown in Appendix A.

On aggregate, firm default and bank failure rates increase, and loan supply contracts (lower panel of Figure 5). Notably, the effect on bank failure is very short lived: on impact, realized loan payoffs decline, such that the failure rate increases by around 0.03 percentage points. However, since bank regulation is binding immediately, banks reduce their deposit supply going forward, such that the failure rate reverts to its steady state level in the quarter after the shock. The reason behind this short-lived effect is that banks have no incentive to accumulate equity in our model, such that there is no depletion of equity buffers stretching over multiple periods after the shock. The contraction of deposits after a tax shock is quite similar to the medium-run reduction in liquidity supply after permanent tax increases.

Figure 5: Effect of Carbon Tax Shock: Aggregates



Notes: Impulse response to a 1\$/ToC tax shock. Black represents the case of constant capital requirements. Red represents the optimal simple rule $\varphi_\kappa^c = 0.4$ and $\varphi_\kappa^f = -0.1$. The dashed lines refer to fossil energy producers.

Optimal Bank Regulation. Having established the sectoral and macroeconomic effects of tax shocks, we next show how bank capital regulation can be used as an economic stabilizer at the aggregate and sectoral level. We allow for a differentiated response of clean and fossil capital requirements, setting $\kappa_t^b = \kappa^{sym}$ and $\kappa_t^n = \kappa^{sym}$ for tractability.

We focus on simple (type-specific) rules:

$$\kappa_t^c = \kappa^{sym}(1 + \varphi_\kappa^c \widehat{\tau}_t) \ , \tag{26}$$

$$\kappa_t^g = \kappa^{sym}(1 + \varphi_\kappa^g \widehat{\tau}_t) \ . \tag{27}$$

Here, $\widehat{\tau}_t \equiv \tau_t - \tau$ represents the surprise tax change and κ^{sym} is the welfare-maximizing medium-run capital requirement, which is still approximately 8% under a 30\$/Toc tax. Within this parametric specification, we maximize utilitarian welfare over the parameter φ_κ^c and φ_κ^f that govern the cyclical response of clean and fossil capital requirements, respectively. We obtain a value of $\varphi_\kappa^c = 0.45$ and $\varphi_\kappa^f = -0.15$. This implies that banks are required to hold more equity for a clean loan after the shock.

In Figure 4, the response of sectoral variables to tax shocks under differentiated dynamic capital requirements is indicated in red. The bottom left panel shows that the increase in the clean capital requirement is substantial. There is a similarly large decline in the fossil requirement to slightly more than 7%. The reason behind this is that the tax shock, having effects similar to a positive productivity shock for the clean energy sector, generates a clean credit expansion. As shown in the bottom right panel of Figure 4, a dynamic increase in clean capital requirements reduces clean leverage relative to the time-invariant policy and keeps the clean default rate below steady state for several periods. At the same time, clean investment increases by slightly less than it would otherwise do. Fossil leverage and default rate shows the opposite pattern: under the temporarily relaxed capital requirements, leverage is slightly higher and default risk remains elevated slightly longer. The greenium mainly reflects temporary derivations from symmetric treatment in banks' credit supply. Clean loans become more expensive to extend and their yield increases relative to fossil loans.

The aggregate effects of dynamically adjusted capital requirements are shown in Figure 5, also marked in red. Since the fossil energy share is around 73.5% under a medium-run carbon tax of 30\$/ToC, the coefficients $\varphi_\kappa^c = 0.4$ and $\varphi_\kappa^f = -0.1$ imply an aggregate increase of capital requirements, such that the bank failure rate drops below its initial level after the shock. At the same time, banks are induced to hold more fossil loans with high expected payoffs, which enables them to expand their balance sheet. This implies that deposit supply stays almost constant, in contrast to the substantial decline they experience do under a constant policy. The dynamically differentiated capital requirement has otherwise only small effects on macroeconomic aggregates such as investment, inflation, and corporate default. It does however imply a slightly smaller contraction in GDP.

6 Conclusion

In this paper, we have proposed an E-DSGE model with two layers of default to study optimal capital regulation and climate policy in a joint framework. Calibrating the model to match salient features of financial markets and the transition to net zero, we show that differentiated capital requirements for clean and fossil loans have a quantitatively negligible effect on carbon emissions while inflicting non-negligible side effects on bank failure risk and liquidity provision, rendering them an ill-suited instrument to initiate a transition to net zero. The model also provides a useful laboratory to study interactions between capital requirements and carbon taxes. While anticipated carbon taxes have no sector-specific effect in the medium-run, optimal bank regulation is slightly more lenient to address adverse effects of carbon taxes on liquidity provision to households. However, differentiated capital requirements are welfare improving if they respond adequately to carbon tax shocks. A surprise increase of carbon taxes by 1\$/ToC induces the bank regulator to increase (decrease) the clean (fossil) capital requirement by 1.2 (0.7) percentage points. This policy alleviates excessive risk-taking incentives that a surprise carbon tax increase exerts on clean firms and reduces aggregate default rates.

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A Model Appendix

This section provides additional analytical steps to derive banks' loan supply as well as firms' loan demand and investment.

Firm FOCs. Firms maximize profits, taking banks' loan pricing schedule as given. Similar to fossil energy firms, the first-order conditions for clean energy producers read

$$\frac{\partial q(\overline{m}^c_{t+1})}{\partial l^c_{t+1}}\left(l^c_{t+1} - (1-\chi)\frac{l^c_t}{\pi_t}\right) + q(\overline{m}^c_{t+1}) = \mathbb{E}_t\left[\frac{\widetilde{\Lambda}_{t,t+1}}{\pi_{t+1}}\Big(\chi(1-F(\overline{m}^c_{t+1})) + (1-\chi)q(\overline{m}^c_{t+2})\Big)\right], \tag{A.1}$$

$$\psi^c_t = \frac{\partial q(\overline{m}^c_{t+1})}{\partial k^c_{t+1}}\left(l^c_{t+1} - (1-\chi)\frac{l^c_t}{\pi_t}\right) + \mathbb{E}_t\left[\widetilde{\Lambda}_{t,t+1}\Big((1-\delta_K)\psi^c_{t+1} + p^c_{t+1}\big(1-G(\overline{m}^c_{t+1})\big)\Big)\right]. \tag{A.2}$$

The first-order condition for clean investment does not depend on compliance costs, but is otherwise identical to fossil investment. For non-energy producers we obtain

$$\frac{\partial q(\overline{m}^n_{t+1})}{\partial l^n_{t+1}}\left(l^n_{t+1} - (1-\chi)\frac{l^n_t}{\pi_t}\right) + q(\overline{m}^n_{t+1}) = \mathbb{E}_t\left[\frac{\widetilde{\Lambda}_{t,t+1}}{\pi_{t+1}}\Big(\chi(1-F(\overline{m}^n_{t+1})) + (1-\chi)q(\overline{m}^n_{t+2})\Big)\right], \tag{A.3}$$

$$\psi^n_t = \frac{\partial q(\overline{m}^n_{t+1})}{\partial k^n_{t+1}}\left(l^n_{t+1} - (1-\chi)\frac{l^n_t}{\pi_t}\right) + \mathbb{E}_t\left[\widetilde{\Lambda}_{t,t+1}\Big((1-\delta_K)\psi^n_{t+1} + p^n_{t+1}\big(1-G(\overline{m}^n_{t+1})\big)\Big)\right]. \tag{A.4}$$

Since there is a continuum of clean and fossil energy firms, individual loans have a negligible effect on the failure probability of an individual bank. The first-order condition does not feature the derivative of $\overline{\mu}_{t+1}$ with respect to individual loans. Furthermore, the loan supply of an individual bank has no effect on the default risk of individual firms. The break-even condition for loans, thus, takes firm default risk as given.

Slope of Loan Price. We can express the derivative of the loan price used in firm (12) and (13) as $\frac{\partial q^\tau_t}{\partial l^\tau_{t+1}} = \frac{\partial q^\tau_t}{\partial \overline{m}^\tau_{t+1}}\frac{\overline{m}^\tau_{t+1}}{l^\tau_{t+1}}$ and $\frac{\partial q^\tau_t}{\partial k^\tau_{t+1}} = \frac{\partial q^\tau_t}{\partial \overline{m}^\tau_{t+1}}\frac{\overline{m}^\tau_{t+1}}{k^\tau_{t+1}}$, respectively. The derivative of the loan price (6) with respect to the risk choice is thus given by

$$\frac{\partial q^\tau_t}{\partial \overline{m}^\tau_{t+1}} = -\mathbb{E}_t\left[\frac{(1-\kappa^\tau_t)\Xi_t + \overline{\Lambda}_{t+1}}{\pi_{t+1}}\Big(\chi\frac{G(\overline{m}^f_{t+1})}{(m^f_{t+1})^2} + \varphi F'(\overline{m}^f_{t+1})\Big)\right]. \tag{A.5}$$

Taken together, an increase in loans outstanding decreases loan prices, while and increase in investment increases them, since it is less likely that revenues $(m^\tau_t p^\tau_t k^\tau_t)$ fall short of repayment obligations, ceteris paribus.

Banks FOCs. The profit maximization problem is given by

$$\max_{\{l_{t+1}^{\tau}\}} \frac{\sum_{\tau}(1-\kappa_t^{\tau})\mathbb{E}_t[\mathcal{R}_{t+1}^{\tau}]l_{t+1}^{\tau}}{1+r_t^D} - \sum_{\tau} q_t^{\tau} l_{t+1}^{\tau}$$
$$+ \mathbb{E}_t\left[\Lambda_{t+1}\int_{\overline{\mu}_{t+1}}^{\infty} \mu_{t+1}\sum_{\tau}\mathcal{R}_{t+1}^{\tau}l_{t+1}^{\tau} - (1-\kappa_t^{\tau})\mathbb{E}_t[\mathcal{R}_{t+1}^{\tau}]l_{t+1}^{\tau} dF(\mu_{t+1})\right] ,$$

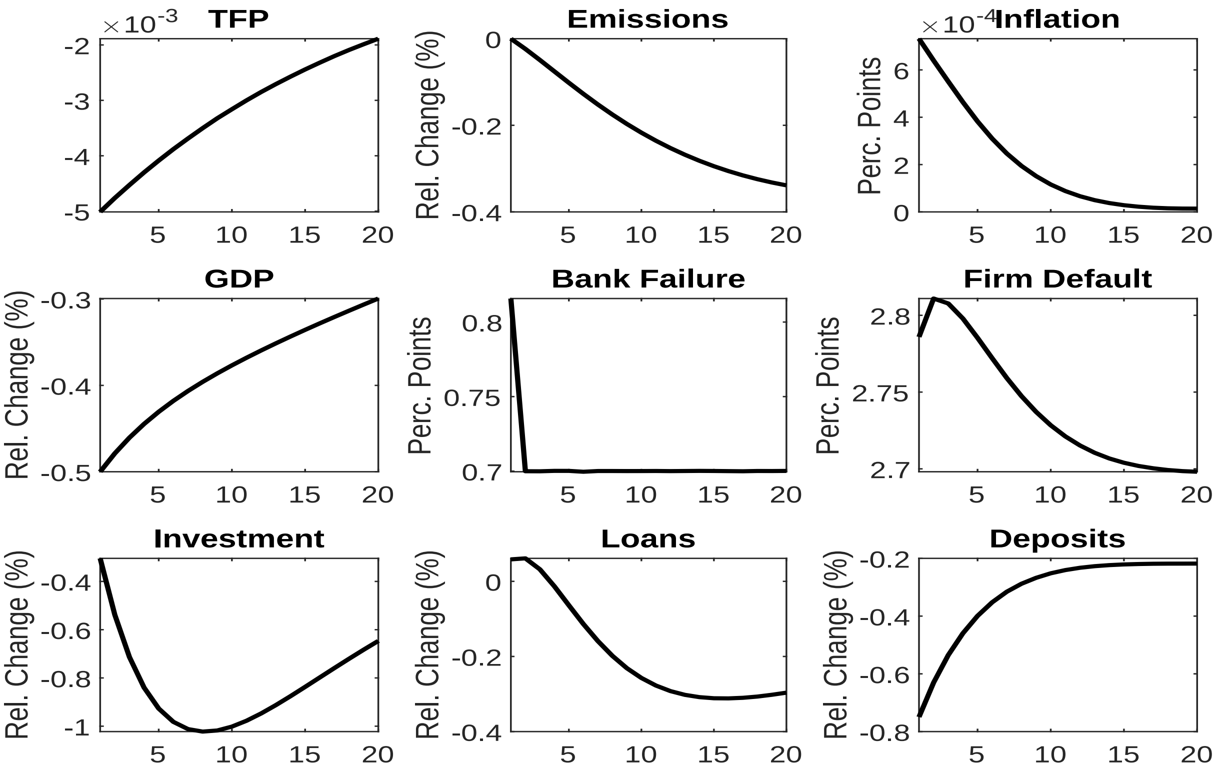
where we already plugged in the binding bank equity constraint (5). Taking FOC w.r.t. l_{t+1}^{τ}, we get

$$\frac{(1-\kappa_t^{\tau})\mathbb{E}_t[\mathcal{R}_{t+1}^{\tau}]}{1+r_t^D} - q_t^{\tau} + \mathbb{E}_t\left[\Lambda_{t+1}\left\{(1-G(\overline{\mu}_{t+1}))\mathcal{R}_{t+1}^{\tau} - (1-F(\overline{\mu}_{t+1}))(1-\kappa_t^{\tau})\mathcal{R}_{t+1}^{\tau}\right\}\right] = 0 .$$

Rearranging for q_t^{τ} yields equation (6).

TFP Shocks. In Figure 6, we show the transmission of a negative one standard deviation shock to TFP. This increases inflation and GDP on impact as in the textbook New Keynesian model. Aggregate investment contracts, such that emissions slowly decrease. On the financial side, the bank failure and firm default rate increase by around 0.1 percentage points.

Figure 6: Effect of Carbon Tax Shock with $\gamma_D = 0.5$: Sectors



B Robustness

This section presents several robustness checks regarding the parameterization of the baseline model. We focus on the risk-taking incentives by banks and firms and on the valuation of deposits' liquidity services, since these crucially shape the transmission of bank capital regulation in our model.

B.1 The Role of Bank and Firm Risk

First, we recalibrate the model to match an annualized firm default rate of 6% and a bank failure rate of 2%. Both moments are substantially higher than in the baseline calibration, where we target a firm default rate of 2.7% and a bank failure rate of 0.7%. The elevated bank failure can matched relatively easily by simply increasing $\varsigma_\mu = 0.0315$. Consequently, the effects of setting $\kappa^f = 1$ and increasing carbon taxes are virtually identical to the baseline calibration (see Table B.1.1).

Table B.1.1: Medium-Run Effects of Selected Policies, High Bank Risk

Moment	Baseline	$\kappa^f = 1$	3.00$ tax	0.13$ tax
Clean Spread	123bp	116bp	123bp	123bp
Fossil Spread	123bp	172bp	123bp	123bp
Clean Leverage	40.0%	40.1%	40.0%	40.0%
Fossil Leverage	40.0%	38.8%	40.0%	40.0%
Clean Default	2.7%	2.8%	2.7%	2.7%
Fossil Default	2.7%	1.9%	2.7%	2.7%
Fossil Capital Share	80.00%	79.20%	79.20%	79.96%
Δ GHG Stock	-	-1.34%	-10.46%	-1.34%
Damage/GDP	5.23%	5.16%	4.69%	5.16%
Bank Failure Prob	2.0%	0%	2.0%	2.0%
Deposit Spread	-126bp	-147bp	-126bp	-126bp
Δ Welfare	-	-0.09%	+1.55%	+0.22%

To obtain a firm default rate of 6%, we decrease firmowners' time preference factor to $\widetilde{\beta} = 0.976$ and increase the standard deviation of the firm risk shock to $\varsigma_M = 0.25$, which ensures that leverage matches its target. In the case of substantially elevated default risk, firms accumulate less capital and GDP declines. Thus, we adjust the climate damage parameter to $d_0 = 1.7e - 04$ to keep the damage-to-GDP ratio at its baseline. Lastly, we slightly reduce the standard deviation of bank risk to $\varsigma_\mu = 0.0277$ to obtain a bank failure rate of 0.7%.

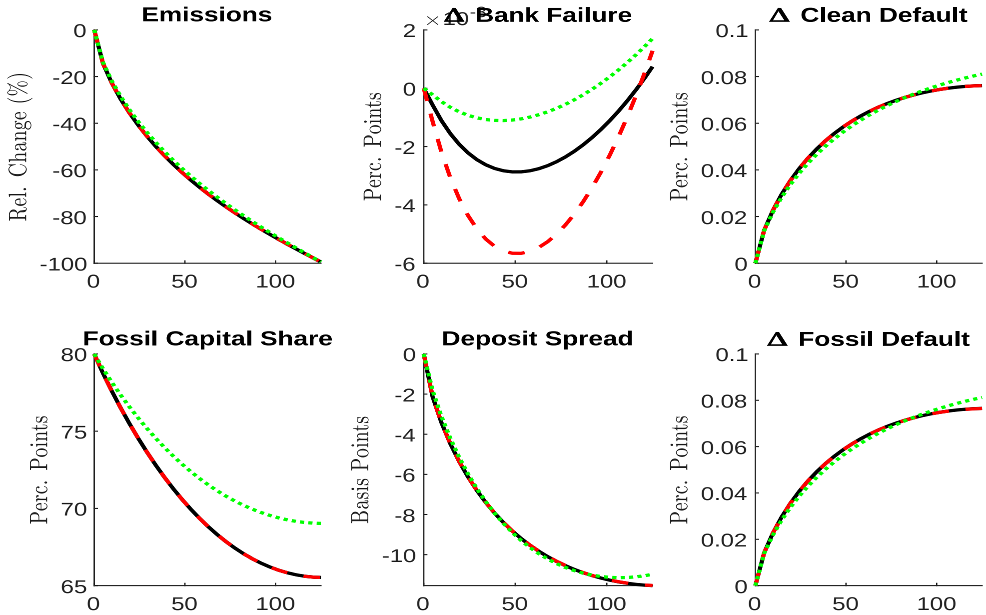
Table B.1.2: Medium-Run Effects of Selected Policies, High Firm Risk

Moment	Baseline	$\kappa^f = 1$	2.17$ tax	0.06$ tax
Clean Spread	519bp	515bp	519bp	519bp
Fossil Spread	519bp	554bp	519bp	519bp
Clean Leverage	40.0%	40.0%	40.0%	40.0%
Fossil Leverage	40.0%	38.9%	40.0%	40.0%
Clean Default	6.0%	6.0%	6.0%	6.0%
Fossil Default	6.0%	5.1%	6.0%	6.0%
Fossil Capital Share	80.00%	79.56%	79.56%	79.96%
Δ GHG Stock	-	-0.77%	-8.20%	-0.77%
Damage/GDP	5.18%	5.14%	4.48%	5.14%
Bank Failure Prob	0.7%	0%	0.7%	0.7%
Deposit Spread	-128bp	-147bp	-128bp	-138bp
Δ Welfare	-	-0.11%	+1.37%	+0.14%

The second column of Table B.1.2 shows that the firm sector is less responsive to changes in capital requirements. The fossil capital share declines by less than half a percentage point and the emission reduction is merely 0.77%, compared to the baseline case (1.33%). Our baseline results on the efficacy of fossil penalizing capital requirements can thus be interpreted as a conservative approximation with respect to private sector default risk.

We again turn to the effects of carbon taxes on bank regulation in a second step. Quantitatively, the bank failure rate is still not affected by carbon taxes in a relevant way, as the upper panel of Figure B.1.1 shows. The reaction of medium-run corporate default rates also does not depend on the initial level of bank or firm default risk. Merely the fossil capital share is less responsive to carbon taxes if firm risk is calibrated to a higher level, since investment elasticities are generally smaller in a high default risk environment.

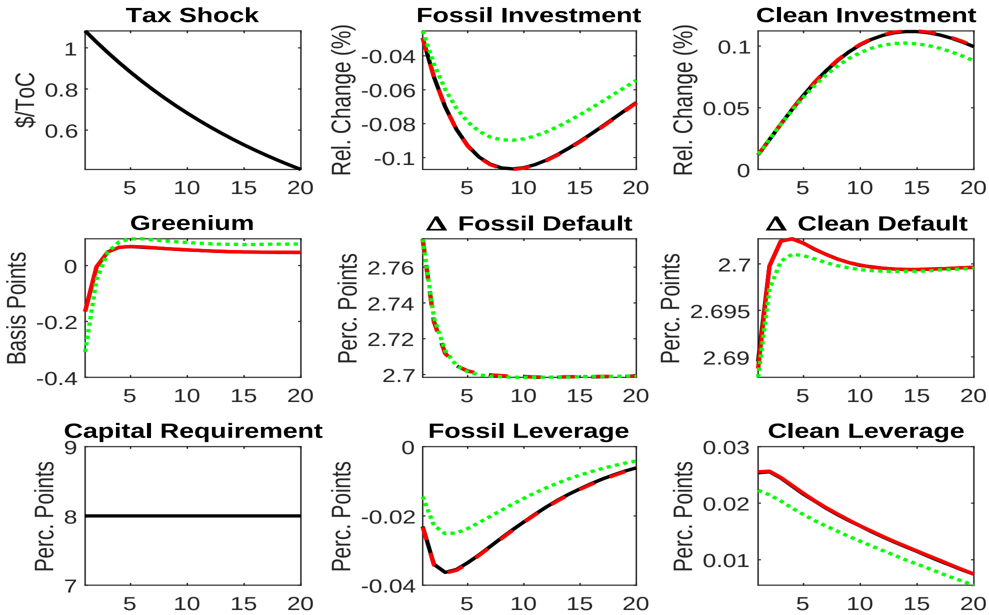
Figure B.1.1: Medium-Run Effects of Carbon Taxes with High Risk



Notes: The carbon tax on the x-axis is expressed in $/ToC. Dashed red lines refer to higher bank risk, dotted green lines to higher firm risk, and solid black lines to the baseline.

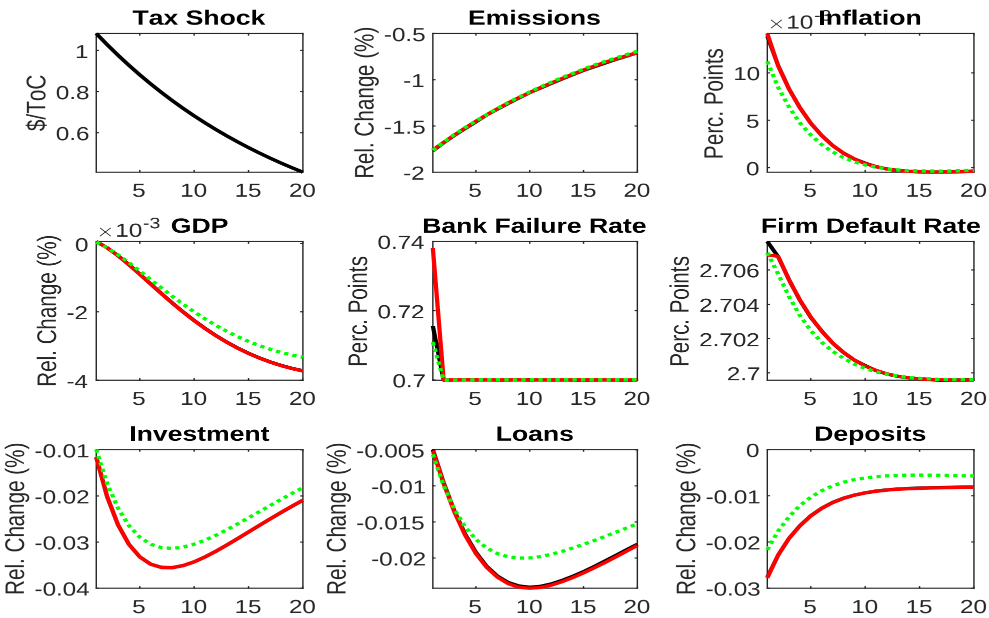
Similar to the effects of carbon taxes in the medium-run, Figure B.1.2 and Figure B.1.3 show that high firm risk dampens the reaction of the firm sector to tax shocks. The sign and shape of all variables is however consistent with the baseline. Elevated bank risk only differs from the baseline in the uptake of the bank failure rate after a shock. The response is substantially larger. All firm-related variables and all macro aggregates are virtually identical to the baseline calibration.

Figure B.1.2: Effect of Carbon Tax Shock with High Risk: Sectors



Notes: Impulse response to a 1\$/ToC tax shock. Dashed red lines refer to higher bank risk, dotted green lines to higher firm risk, and solid black lines to the baseline.

Figure B.1.3: Effect of Carbon Tax Shock with High Risk: Macro Variables



Notes: Impulse response to a 1\$/ToC tax shock. Dashed red lines refer to higher bank risk, dotted green lines to higher firm risk, and solid black lines to the baseline.

B.2 Low Elasticity of Deposit Demand

This section provides a sensitivity analysis with respect to households' valuation of liquidity services. Specifically, we decrease its curvature parameter to $\gamma_D = 0.5$. To ensure a fair comparison to the benchmark calibration, we adjust the deposit utility weight $\omega_D = 0.0375$ to match the deposit spread and set the DIA loss parameter $\zeta = 0.02$ to render $\kappa^{sym} = 0.08$ optimal.

As Table B.2.1 shows, subjecting fossil loans to a 100% equity requirement has almost identical effects on fossil energy firms and emission reductions as under the baseline calibration (Table 3). However, the deposit spread widens by less than under the baseline calibration. Consequently, the clean spread declines by only 2bp compared to an 8bp reduction in the baseline. The leverage ratio and default rate of clean firms are, thus, not visibly affected by this policy. Nevertheless, the 100% equity requirement is welfare reducing in our model. The carbon tax necessary to obtain the same fossil capital share (2.75\$/ToC) or the same emission reduction (0.14\$/ToC) are similar to the baseline.

Table B.2.1: Medium-Run Effects of Selected Policies, $\gamma_D = 0.5$

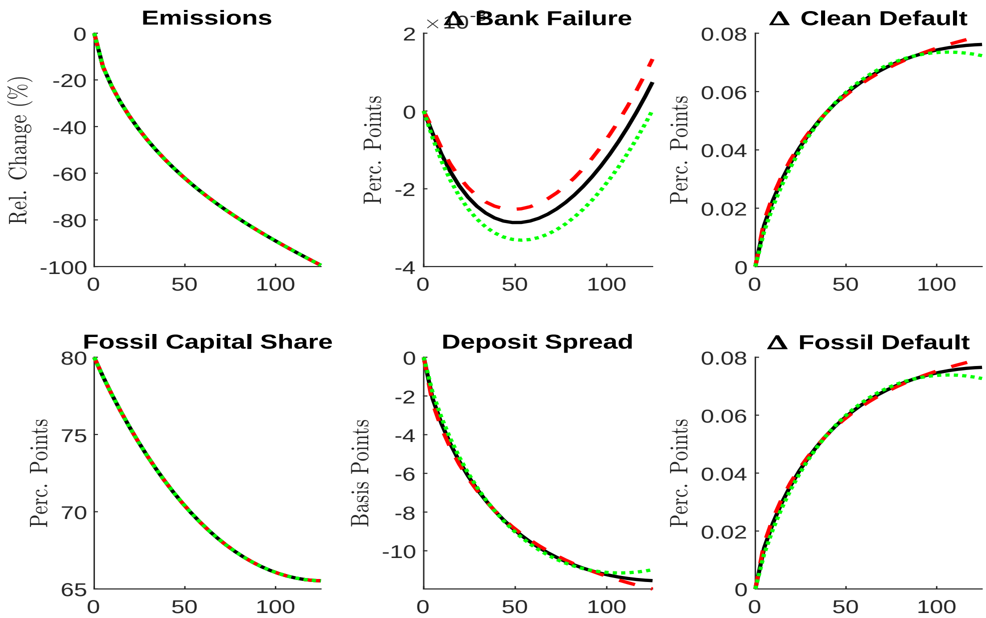
Moment	Baseline	$\kappa^f = 1$	2.75\$ tax	0.14\$ tax
Clean Spread	123bp	121bp	123bp	123bp
Fossil Spread	123bp	172bp	123bp	123bp
Clean Leverage	40.0%	40.0%	40.0%	40.0%
Fossil Leverage	40.0%	38.8%	40.0%	40.0%
Clean Default	2.7%	2.7%	2.7%	2.7%
Fossil Default	2.7%	1.9%	2.7%	2.7%
Fossil Capital Share	80.00%	79.27%	79.27%	79.96%
Δ GHG Stock	-	-1.39%	-9.89%	-1.39%
Damage/GDP	5.23%	5.15%	4.72%	5.16%
Bank Failure Prob	0.7%	0%	0.7%	0.7%
Deposit Spread	-127bp	-134bp	-127bp	-127bp
Δ Welfare	-	-0.14%	+1.47%	+0.23%

In Table B.2.2, we also report results for the case of $\gamma_D = 3$, where we also recalibrate $\omega_D = 0.625$ to match the average deposit spread. Unsurprisingly, the effect of setting $\kappa^f = 1$ on deposit spreads is larger than in the baseline, and welfare declines by slightly more.

Table B.2.2: Medium-Run Effects of Selected Policies, $\gamma_D = 3$

Moment	Baseline	$\kappa^f = 1$	2.75$ tax	0.11$ tax
Clean Spread	124bp	121bp	124bp	124bp
Fossil Spread	124bp	172bp	124bp	124bp
Clean Leverage	40.0%	40.0%	40.0%	40.0%
Fossil Leverage	40.0%	38.8%	40.0%	40.0%
Clean Default	2.7%	2.7%	2.7%	2.7%
Fossil Default	2.7%	1.9%	2.7%	2.7%
Fossil Capital Share	80.00%	79.10%	79.10%	79.97%
Δ GHG Stock	-	-1.22%	-11.34%	-1.22%
Damage/GDP	5.23%	5.12%	4.64%	5.16%
Bank Failure Prob	0.7%	0%	0.7%	0.7%
Deposit Spread	-125bp	-164bp	-125bp	-125bp
Δ Welfare	-	-0.25%	+1.66%	+0.20%

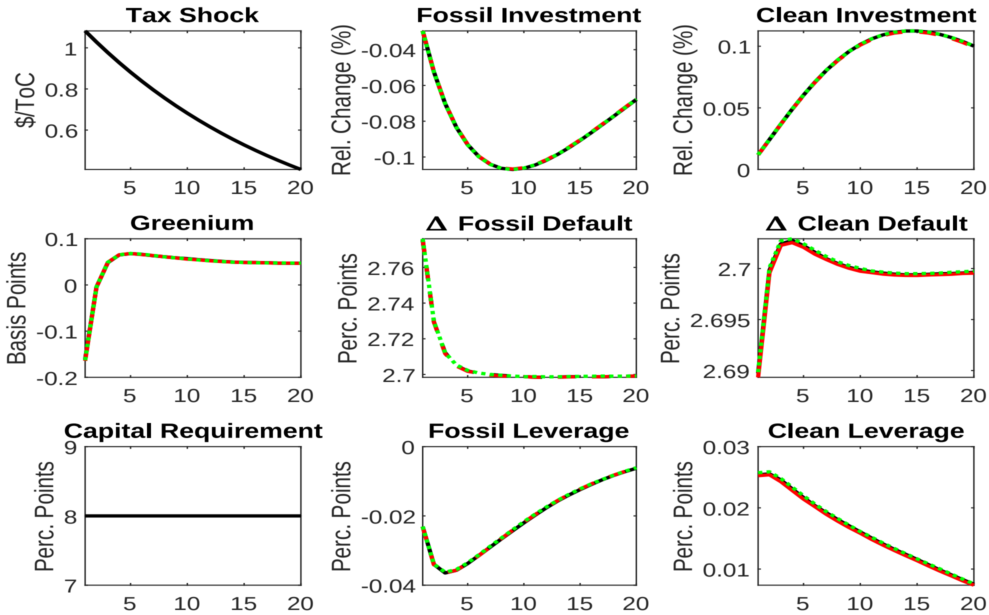
Figure B.2.1: Medium-Run Effects of Carbon Taxes with $\gamma_D = 0.5$ and $\gamma_D = 3$



Notes: The carbon tax on the x-axis is expressed in $/ToC. Dashed red lines refer to $\gamma_D = 0.5$, dotted green lines to $\gamma_D = 3$, and solid black lines to the baseline.

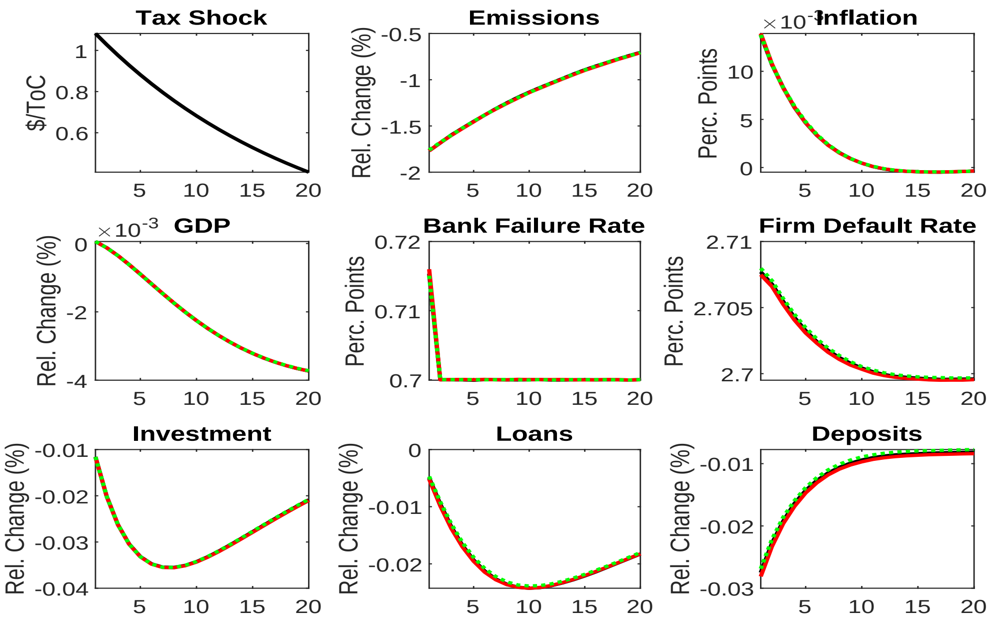
Figure B.2.1 shows that the pass-through of carbon taxes is not materially affected by changes in the elasticity of liquidity services. Likewise, in Figure B.2.2 and Figure B.2.3, we show that the effect of a 1$/ToC tax shock is similar to the baseline case.

Figure B.2.2: Effect of Carbon Tax Shock with $\gamma_D = 0.5$ and $\gamma_D = 3$: Sectors



Notes: Impulse response to a 1$/ToC tax shock. Dashed red lines refer to $\gamma_D = 0.5$, dotted green lines to $\gamma_D = 3$, and solid black lines to the baseline.

Figure B.2.3: Effect of Carbon Tax Shock with $\gamma_D = 0.5$ and $\gamma_D = 3$: Macro Variables



Notes: Impulse response to a 1$/ToC tax shock. Dashed red lines refer to $\gamma_D = 0.5$, dotted green lines to $\gamma_D = 3$, and solid black lines to the baseline.