Climate Minsky Moments and Endogenous Financial Crises*

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Abstract

How does a shift in climate policy affect financial stability? We develop a quantitative macroeconomic model with carbon taxes and endogenous financial crises to study so-called "Climate Minsky Moments". By reducing asset returns, an accelerated transition to net zero initially elevates the crisis probability substantially. However, carbon taxes enhance long-run financial stability by diminishing the relative size of the financial sector. Quantitatively, the net financial stability effect is only negative for higher social discount rates. Even then, the welfare effects of "Climate Minsky Moments" are, at most, second-order relative to the real costs and benefits of an accelerated transition.

Keywords: Climate Policy, Financial Stability, Financial Crises, Transition Risk, Non-Linearities.

JEL classification: E32, E44, G20, Q52, Q58

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1 Introduction

Does the net zero transition increase financial fragility and, if so, by how much? Answering these questions is crucial for financial regulation over the next decades, which may be characterized by a large shift away from emission-intensive technologies. Ambitious taxes on carbon emissions could negatively affect the macroeconomy and asset prices by triggering a sharp and permanent drop in the productivity of emission-intensive assets, also known as asset stranding. A shift in climate policy can then give rise to "Climate Minsky Moments", in which a sudden reduction in asset prices raises the concern that financial intermediaries are unable to repay depositors, triggering a financial crisis.[1] However, as no country has yet introduced sufficiently stringent climate policies, evaluating the relevance of "Climate Minsky Moments" for financial stability, the macroeconomy, and welfare using historical data is practically infeasible.

Against this background, we develop a nonlinear quantitative macroeconomic model with endogenous financial crises and carbon taxes to study the threat of "Climate Minsky Moments". Our model is centered on the notion that financial intermediaries are run-prone in the spirit of Diamond and Dybvig (1983). Specifically, the possibility of a systemic run on the financial system is fully endogenous and depends on the macro-financial environment. Based on the seminal work by Nordhaus (2008), the model features carbon emissions into the production process, carbon taxes, and an endogenous choice between clean and dirty technology. Using our macro-finance-climate model, we evaluate how a climate policy that reaches net zero carbon dioxide emissions by 2050 - consistent with the Paris Agreement - affects financial stability and macroeconomic aggregates, both in the short- and long-run. This quantitative evaluation of endogenous financial fragility adds a novel element to the ongoing debate on financial stability in the context of climate policy.[2] We then examine how the threat of "Climate Minsky Moments" impacts welfare, comparing it to the real costs and benefits of the net zero transition.

The two key building blocks of our framework are the financial sector with endogenous financial crises and firms' technology choice, which is affected by the climate policy stance. Financial intermediaries are subject to an endogenous leverage constraint based on Adrian and Shin (2014) and Nuño and Thomas (2017). Adding risk shocks in the spirit of Christiano et al. (2014) introduces time-variation into the leverage constraint. The financial sector then faces occasional runs, driven by depositors' state-dependent willingness to roll over intermediaries' liabilities, similar to Gertler et al. (2020). Therefore, the probability of such a self-fulfilling run depends on the financial sector's leverage and the price of capital, which is directly affected by climate policy.

Climate policy enters the model through the production sector. Firms emit carbon

[1] The term "Climate Minsky Moments" was coined by Carney (2016) in the spirit of Minsky (1977).

[2] The current debate on financial stability implications of climate policies centers around negative credit supply effects, while abstracting from financial crises.

dioxide during the production process. Emissions are taxed by the fiscal authority, but we allow for the adoption of a less productive clean production technology, which reduces the emission intensity at the macroeconomic level (Nordhaus, 2008). The productivity losses from adopting and operating the clean technology have a negative effect on welfare. At the same time, carbon taxes increase welfare by curbing global temperature increases. In addition to these real costs and benefits of the net zero transition, climate policy has an additional welfare-relevant effect due to its impact on the frequency of financial crises.

Climate policy affects financial stability through two opposing mechanisms. Increasing the carbon tax results in asset stranding due to the combination of a higher carbon tax bill and the productivity losses from using the less productive clean technology. The marginal product of capital declines, which reduces the market value of assets held by the financial sector. This endogenously tightens the financial sector's leverage constraint.[3] The resulting downward pressure on asset prices elevates the likelihood of a run on the financial sector: the probability of "Climate Minsky Moments" increases. On the other hand, by reducing the marginal product of capital, higher carbon taxes also reduce the incentives to accumulate capital.[4] Consequently, less capital needs to be absorbed during a crisis, which stabilizes the asset price and increases financial stability: the probability of "Climate Minsky Moments" decreases. Which of these opposing mechanisms dominates is a quantitative question.

To provide a quantitative assessment, we embed this framework in a New Keynesian general equilibrium setup, which improves the model's fit to macro-financial dynamics. The model is matched to salient features of macro-financial cycles and the macroeconomic effects of climate policy. Global temperatures are linked to cumulated emissions and we assume that they inflict utility losses on households (Acemoglu et al., 2012), as it permits an exact welfare decomposition of the net zero transition into climate gains, productivity losses, and Climate Minsky moments. With that said, we show that the key positive and normative implications of Climate Minsky Moments are very similar in an extension with physical risk, which incorporate a feedback from higher global temperatures to the macroeconomy and the financial sector in the spirit of integrated assessment models. Solving our model in its nonlinear specification with global methods allows us to calculate the crisis probability along different climate policy paths. Our analysis reveals that both opposing mechanisms matter but at different time horizons.

We show that the net zero transition comes with an elevated crisis probability in the early stages of the transition due to asset stranding. To quantify the financial stability effects, we compare the current trajectory to a stringent policy path aligned with the Paris

[3]Jung et al. (2024) show that ambitious climate policy induces loan portfolio losses between 1 and 6% for US banks. More generally, institutional investors are aware that ambitious climate policy has detrimental effects on asset values (Krueger et al., 2020).

[4]Kaenzig (2023) provides evidence that positive carbon tax shocks decrease aggregate investment. Berthold et al. (2023) show that such positive carbon shocks also tighten financing conditions.

Agreement. For the current trajectory, we extrapolate the historical reduction in global emission intensities observed between 1990 and 2023, which implies that net zero would be reached in 2090. In our baseline calibration, a carbon tax of around 140 dollars per ton of carbon dioxide ($/tCO2) achieves net zero. The *Paris-aligned* transition instead assumes that the climate policy suddenly shifts in 2025 to a tax path designed to reach net zero already in 2050. This path is consistent with the Paris Agreement, implying that global surface temperatures will not increase by more than $2°C$ by the end of the century. The sudden shift onto a steeper carbon tax path can render the initial financial sector leverage and size unsustainable: the (annualized) crisis probability increases initially to almost 3% in the *Paris-aligned* transition, while the crisis probability is only 2.1% in the current trajectory. Thus, we observe a substantial initial increase in financial fragility. The crisis probability then slowly declines to its lower long-run level, which is reached shortly after 2050 *Paris-aligned* path, while it is only reached around 2090 on the current trajectory.

Assessing the long-run implications, we show that permanently higher carbon taxes enhance financial stability. The reason behind this perhaps surprising result is that there is less capital accumulation if carbon taxes are high.[5] The financial sector is smaller and less leveraged in the long-run, while households are willing to absorb a larger share of the capital shock if intermediaries face deleveraging pressures. Our model captures a positive relationship between capital accumulation and the demand for financial services. This notion goes back at least to Robinson (1952), who summarized the idea as "where enterprise leads, finance follows". As a consequence, intermediaries can deleverage more easily in a crisis without having to sell capital at fire sale prices. This effectively increases resilience in the financial sector. The probability of a financial crisis declines from around 2.0% in the long-run equilibrium without climate policy to 1.4% in the long-run equilibrium with net zero emissions. Note that the *Paris-aligned* transition profits earlier from this reduced financial stability than the *current trajectory*.

Our non-linear model reveals that a monotonic transition path can have non-monotonic financial stability effects. To determine the net financial stability effect of these opposing mechanisms, we introduce a metric of financial stability that summarizes the occurrences of crises along different transition paths. The *excess crisis probability* is defined as the discounted difference between the crisis probability under the *Paris-aligned* transition and the *current trajectory*. As in all climate policy assessments, choosing the appropriate discount rate for future financial stability gains is a highly non-trivial normative issue. We do not take a stand on the appropriate social discount rate and compute the excess crisis probability over a reasonable range of discount rates. The excess crisis probability is positive for sufficiently high social discount rates, as the elevated crisis probability in

[5] We show in Appendix D.1 that the negative relationship between capital accumulation and carbon taxes emerges in various model classes commonly used in assessing climate policies.

the short run triggered by the sudden shift on a stringent carbon tax path dominates. Notably, the excess crisis probability turns negative if the social discount rate exceeds 1.5% per annum. If future financial stability gains associated with less capital accumulation are not discounted too heavily, ambitious climate policy positively affects financial stability. This rejects the notion of an unambiguous trade-off between financial stability and climate policy objectives. The time pattern of "Climate Minsky Moments" implied by our model bears a striking resemblance to the time pattern of costs and benefits of ambitious climate policy action more generally.

At the same time, our results also raise the question of how relevant "Climate Minsky Moments" are when compared to the productivity losses of clean technologies and temperature gains. Using our structural model, we benchmark the welfare relevance of "Climate Minsky Moments" against the real costs and gains of a transition to net zero. First, we demonstrate that the welfare gains of "Climate Minsky Moments" are inversely related to the *excess crisis probability* and are positive (negative) for a low (high) discount rate. However, our model shows that the welfare effects of "Climate Minsky Moments" are dwarfed by the costs of switching to emission-free technologies. For example, assuming a high social discount rate of 4% p.a., "Climate Minsky Moments" reduce welfare by around 0.008%, while productivity losses reduce welfare by slightly more than 1%. The reason is that the negative impact on financial stability is limited and relatively short-lived, even for ambitious carbon tax paths. Therefore, it comes as little surprise that the welfare effects of "Climate Minsky Moments" are second-order relative and do not substantially affect the key trade-off between productivity losses and temperature gains.

Reassuringly, the likelihood of "Climate Minsky Moments" and their associated welfare results are very robust to reasonable variations in the climate block. Specifically, we discuss how the following dimensions affect our findings: a) physical risk associated with global warming, b) technological change directed at emission reduction activities, c) trend growth that affects climate costs, d) various modifications to the production sector, such as a clean-dirty two-sector structure or a model with energy as production input, e) fiscal policy that features clean technology subsidies, f) the year at which net zero is reached, g) non-linear carbon tax paths, h) higher cost of operating the clean technology, and i) the cost of global warming. The welfare relevance of "Climate Minsky Moments" remains at most second-order in either case. Taken together, our results push back decisively on the notion that financial stability concerns are a valid reason to delay the net zero transition, irrespective of the social discount rate. Our results instead indicate that "Climate Minsky Moments" concerns seem a manageable risk, regardless of the exact details of the production sector, climate policy, and the climate block.

As a final step, we evaluate the potential to mitigate financial stability concerns further using the central bank's toolkit. In particular, we study the role of macroprudential policy and monetary policy through the lens of our quantitative model. Notably, the financial cycle is a crucial driver of the financial stability effects associated with stringent climate policies. Specifically, the short-run financial stability and welfare impact of stringent climate policies depend crucially on the initial conditions. If the financial sector is highly levered up before the switch to a Paris-aligned transition, the crisis probability is substantially higher compared to a situation with less leverage. The reason is the financial sector has a smaller equity buffer to absorb the losses due to asset stranding. Therefore, the build-up of macroprudential space or the implementation of climate policies during a period of strong financial fundamentals allows for the mitigation of the likelihood of "Climate Minsky Moments" substantially.

Regarding monetary policy, we show that an expansionary monetary policy stance can soften the initial impact of ambitious climate policy and the crisis probability by lowering the funding costs of the financial sector. Conversely, contractionary monetary policy exacerbates financial fragility at the onset of the transition. We model the monetary policy stance by a deterministic wedge in the interest rate rule. Contractionary monetary policy has a quantitatively greater impact for the same size of the wedge, making an overly tight monetary policy more costly than an overly loose one. This implies that monetary policy should not "lean against the transition" - as we denote a contractionary monetary policy stance in response to the shift on the Paris-aligned path. The reason is that it is too late to contain financial fragility at this point.

Related Literature. Our paper is connected to the fast-growing literature that uses fully-fledged DSGE models with climate policy and frictions in the financial sector (e.g., Diluiso et al., 2021; Annicchiarico et al., 2023; Carattini et al., 2024; Comerford and Spiganti, 2023; Frankovic and Kolb, 2024; Nakov and Thomas, 2023; Airaudo et al., 2024; Fornaro et al., 2024; Dietrich et al., 2024). Carattini et al. (2023) use a two-sector model to show that carbon taxes can negatively affect financial intermediaries' net worth and induce a credit crunch, which motivates sector-specific macroprudential policy. In this context, Priftis and Schoenle (2024) study the interplay of fiscal and macroprudential policies. Giovanardi et al. (2023) and Giovanardi and Kaldorf (2023) model idiosyncratic default and risk-taking in the firm and banking sector to study sector specific central bank collateral policy and bank capital regulation, respectively. Barnett (2023) shows how financial frictions can give rise to fire sales of carbon-intensive assets. Oehmke and Opp (2025) propose an analytically tractable two-sector model of "green" capital requirements and find that, while green capital requirements are unable to induce the transition to net zero, they can alleviate the risk of asset stranding and thus enhance the credibility of an ambitious climate policy path. Our paper differs from these studies as we explicitly consider the systemic risk dimension of climate policy, i.e., implications for financial stability at the aggregate level rather than in a setting with sector-specific capital accumulation. By incorporating the possibility of runs into a climate DSGE model, we can study the role of climate policy for the endogenous occurrence of financial crises.

To incorporate the possibility of “Climate Minsky Moments”, we build on the recent advancements in the macro-finance literature that incorporated endogenous financial crises in macroeconomic models, as in Brunnermeier and Sannikov (2014), Gertler and Kiyotaki (2015), Boissay et al. (2016), Moreira and Savov (2017), and Amador and Bianchi (2024). Our macro-finance model block builds upon Rottner (2023), which combines pro-cyclical leverage dynamics with self-fulfilling runs, as in Gertler et al. (2020), to reconcile key features of financial cycles.[6] Our paper contributes to this literature by incorporating the role of climate policy in this type of model.

We also relate to the literature on the interactions between financial stability and climate policy that uses analytically tractable models. Jondeau et al. (2021) address the risk of fire sales of emission-intensive assets. Döttling and Rola-Janicka (2023) analyze jointly optimal climate and financial policy in the context of our paper. Our contribution is to build a quantitative model, which opens up the possibility of examining the impact of different climate policies on financial stability through a quantitative lens.

An alternative approach taken by several regulators is climate stress tests. Acharya et al. (2023) provide a summary and outlook for climate change stress tests. Specific examples are Jung et al. (2024) and IMF (2022), who evaluate the effects of specific climate change scenarios on the loan portfolio for the US and UK, respectively. Brunetti et al. (2022) review climate stress test results conducted in several jurisdictions. By design, stress tests cannot uncover positive financial stability effects of the transition, as they abstract from the financial sector’s deleveraging incentives along the net zero transition. In contrast, by taking a general equilibrium perspective, we can fully endogeneize the responses of the different economic agents during the transition to net zero. It also opens up the possibility of a welfare analysis to benchmark the welfare impact of “Climate Minsky Moments” against costs and benefits of the net zero transition in the real sector.

2 Model

The model consists of three building blocks related to carbon emissions and climate policy, the financial sector, and the macroeconomy, respectively. Firms can either operate a dirty technology, which is associated with carbon dioxide emissions that contribute to global temperature increases and are subject to carbon taxes, or a less productive clean technology that allows firms to reduce their carbon tax bill. The financial sector embeds an endogenous leverage constraint (Adrian and Shin, 2014; Nuño and Thomas, 2017) in a model with endogenous financial crises as in Gertler et al. (2020), following the setup of Rottner (2023). This representation of financial fragility and climate policy is embedded

[6] The framework features, for instance, ”credit booms gone bust” dynamics (Schularick and Taylor, 2012) and the volatility paradox (Brunnermeier and Sannikov, 2014).

into an otherwise standard New Keynesian setup.

Production Technology and Climate Policy We first describe the production sector, which is the part of the model where carbon dioxide emissions and taxes enter. There is a mass-one continuum of competitive (intermediate) good producers, indexed by $\eta \in (0,1)$. Each firm uses a Cobb-Douglas technology to produce output $Y_t = AK_{t-1}^{\alpha} L_t^{1-\alpha}$ using capital K_t and labor L_t as inputs. Firms can choose to use a dirty technology that emits one unit of carbon dioxide for each unit of output during the production process (Heutel, 2012).

Carbon dioxide emissions are taxed at the (potentially time-varying) rate τ_t^c, such that the after-tax revenues for a dirty firm are given by $(1-\tau_t^c)Y_t$. In order to reduce emissions, firms can adopt a clean technology that is less productive. To capture the idea that firms in some sectors can switch to clean technologies more easily, we assume that the productivity loss can be written as a convex function $b_1\eta^{b_2}$, where $b_1 > 0$ and $b_2 > 1$. This convex form of productivity losses implies that it is almost cost-less to switch for a few sectors, for example financial services that have a very small emission intensity, while it becomes very costly for some sectors - think of aviation, cement, or steel production - to operate in an emission-free fashion.[7]

In this setting, carbon taxes determine the share of firms that use the clean technology: All firms with $b_1\eta^{b_2} < \tau_t^c$ will choose to operate in an emission-free fashion and we can pin down the firm that is indifferent

$$\eta_t^* = \min\left\{ \left(\frac{\tau_t^c}{b_1}\right)^{\frac{1}{b_2}}, 1 \right\}. \tag{1}$$

Consequently, η_t^* is the (time-varying) share of firms that operate the emission-free technology. It clearly increases in the carbon tax. The min-operator captures the idea that all firms choose the clean technology if the tax exceeds $\tau_t^c > b_1$ and we refer to such taxes as consistent with "net zero".

The aggregate productivity loss associated with any given emission tax obtains from integrating the productivity loss for all firms that switch to clean technologies, $\int_0^{\eta_t^*} b_1\eta^{b_2} Y_t d\eta = \frac{b_1}{b_2+1}(\eta_t^*)^{b_2+1} Y_t$. This term enters the resource constraint. Aggregate emissions are therefore given by $(1-\eta_t^*)Y_t$, while the aggregate carbon tax paid by all firms in period t is

[7] One advantage of our formulation with a choice between clean and dirty technologies is that it admits a net zero emission steady state, which is essential for our long-term analysis. A common alternative is to use clean and dirty capital in a CES production formulation without allowing for technological choice. However, this approach (at least without further modification) precludes a net zero emission scenario as some degree of dirty capital is irreplacable. We discuss alternative production functions in greater detail in Section 5.1, where we demonstrate that the effect of stringent climate policy in capital accumulation remains robust across typical specifications for the production function.

given by $\int_{\eta_t^*}^{1} \tau_t^c Y_t d\eta = \tau_t^c(1-\eta_t^*)Y_t$. Carbon tax revenues are rebated to households in a lump sum fashion.[8]

The idea that climate policy negatively affects aggregate productivity in the real sector is closely linked to the concept of "asset stranding". While asset stranding is often modelled in a two-sector ("clean" and "dirty") setup, our model also encompasses a notion of "ease of replacement". Some technologies - think again of aviation, cement, or steel production - are very emission-intensive but are very difficult to replace with clean production processes. Firms in such sectors thus will operate the dirty technology even under high carbon taxes, such that those firms merely pay the tax and there assets are unlikely to "strand".

To link climate policy directly to the accumulation and pricing of capital in our model economy, it is helpful to define the policy-induced return on capital wedge B_t, which summarizes the expenses from carbon taxation and productivity losses per unit of aggregate output:

$$B_t \equiv \tau_t^c (1-\eta_t^*) + \frac{b_1}{b_2+1} (\eta_t^*)^{b_2+1} \ . \tag{2}$$

The realized return on investment is given by $R_t^K = [(1-\delta)Q_t + Z_t]/Q_{t-1}$. Taking the price of the intermediate good p_t as given, the first-order conditions for capital and labor can be expressed as:

$$Z_t = (p_t - B_t)\alpha \frac{Y_t}{K_{t-1}}, \quad \text{and} \quad W_t = (p_t - B_t)(1-\alpha)\frac{Y_t}{L_t} \ . \tag{3}$$

Since emissions are proportional to total output, climate policy does not affect the aggregate capital share but depresses total factor productivity.

Emissions, Temperature and Climate Damages Emissions are linked to economic damages through increases in global temperatures. Following the climate economics literature, carbon emissions $(1-\eta_t)Y_t$ accumulate into a stock of atmospheric carbon dioxide, which we can map into temperature changes following Fernandez-Villaverde et al. (2024). Specifically, the global temperature change relative to pre-industrial levels, $\Delta\mathcal{T}_t \equiv \mathcal{T}_t - \mathcal{T}_{1850}$, is positively related to cumulated emissions $E_t \equiv E_{2024Q4} + \sum_{s=2025Q1}^{t} e_s$, where E_{2024Q4} corresponds to cumulated emissions up to the last period before the (potential) policy change. Following Fernandez-Villaverde et al. (2024), we approximate this

[8] We also consider a modification in which carbon tax revenues subsidize firms' adoption of clean technologies.

relationship by:

$$\Delta \mathcal{T}_t = \Psi_{CCR} E_t \; . \tag{4}$$

To map global temperature increases into economic damages, we assume that temperature changes inflict a utility loss $\mathcal{D}(\Delta \mathcal{T}_t)$ as in Acemoglu et al., 2012. Utility losses are quadratic in the global temperature increase relative to pre-industrial levels:

$$\mathcal{D}(\Delta \mathcal{T}_t) = \gamma_D (\Delta \mathcal{T}_t)^2 . \tag{5}$$

Such quadratic loss functions are commonly used in integrated assessment models, for example Nordhaus (2008). The key advantage of this specification is that it allows us to cleanly compare the welfare costs of "Climate Minsky Moments" relative to other benefits and costs of curbing global warming without introducing additional interactions between the climate block and the production sector. Temperature changes do not affect any equilibrium outcome, but they affect welfare. We relax this assumption in an extension with physical risk that affects productivity in the real sector. The extension introduces feedback between the global climate and macroeconomic outcomes. Temperature increases are mapped to a damage function that lowers output instead of inflicting utility losses.

Households The representative household consists of workers and managers that have perfect insurance for their consumption C_t. Workers supply labor L_t and earn the wage W_t. Managers run financial intermediaries that return their net worth to the household with a probability of $1 - \theta$. New intermediaries enter each period and receive a transfer from the household, who owns non-financial firms and receives their profits. The variable T_t captures all transfers from the public sector.

Households save in terms of one-period deposits D_t, which promise to pay the gross interest rate of $\overline{R}_t^D$ next period. However, in case of a run, households receive only the fraction $x_t^\star$ of the promised return, which we refer to as the recovery ratio. The realized gross return R_t^D depends on the realization of a run in period t:

$$R_t^D = \begin{cases} \overline{R}_{t-1}^D & \text{if no run takes place in period } t \; , \\ x_t^\star \overline{R}_{t-1}^D & \text{if a run takes place in period } t \; , \end{cases} \tag{6}$$

where x_t^* is the recovery rate on deposits, which we derive below. Additionally, households and intermediaries can invest in the production sector by purchasing capital K_t^H and K_t^B, respectively, that give them ownership in the intermediate good firm. The rental rate on capital is denoted by Z_t, while its market price is denoted by Q_t. Total end-of-period securities are given by $K_t = K_t^H + K_t^B$. Households maximize utility subject to the following period budget constraint:

$$C_t = W_t L_t + D_{t-1} R_t^D - D_t + T_t - Q_t K_t^H + \big(Z_t + (1-\delta) Q_t\big) K_{t-1}^H \ . \tag{7}$$

We assume that households are less efficient in managing securities than intermediaries (Brunnermeier and Sannikov, 2014). As in Gertler et al. (2020), households incur a utility cost from managing capital $\mathcal{C}(K_t^H, K_t)$. As discussed before, damages associated with global temperature increases since pre-industrial times $\mathcal{D}(\Delta\mathcal{T}_t)$ enter the utility function directly. The otherwise standard period utility function is given by:

$$u(C_t, L_t, \frac{K_t^H}{K_t}, K_t, \Delta\mathcal{T}_t) = \frac{C_t^{1-\gamma_C}}{1-\gamma_C} - \frac{L_t^{1+\gamma_L}}{1+\gamma_L} - \mathcal{C}(\frac{K_t^H}{K_t}, K_t) - \mathcal{D}(\Delta\mathcal{T}_t) \ . \tag{8}$$

Capital Management Costs We specify households' capital management costs as

$$\mathcal{C}\Big(\frac{K_t^H}{K_t}, K_t\Big) = \frac{\omega_F}{2}\Big(\frac{K_t^H}{K_t} - \gamma^F\Big)^2 K_t \ . \tag{9}$$

Some properties of this cost function deserve attention, as they turn out to be important in the quantitative analysis. We focus on the case $\frac{K_t^H}{K_t} > \gamma^F$, which holds in all states throughout our numerical simulation. Holding aggregate capital K_t constant, management costs increase in the household capital share ($\frac{\partial\mathcal{C}}{\partial\frac{K_t^H}{K_t}} > 0$) and up to the level $\frac{\omega_F}{2}(1-\gamma^F)^2 K_t$ at which households manage the entire capital stock. Holding the household capital share $\frac{K_t^H}{K_t}$ constant, management costs also increase in aggregate capital. With both partial derivatives being positive, its cross-derivative

$$\frac{\partial^2\mathcal{C}}{\partial\frac{K_t^H}{K_t}\partial K_t} = \omega^F\left(\frac{K_t^H}{K_t} - \gamma^F\right) , \tag{10}$$

is also positive in the numerically relevant region $\frac{K_t^H}{K_t} > \gamma^F$.

These features of the management cost function are consistent with the idea that monitoring investment projects is more costly to households than financial intermediaries, and this cost dis-advantage is larger if the capital stock is large due to economies of scale in monitoring technologies (Diamond, 1984). Put differently, financial intermediation services are in higher demand if the capital stock is large. A larger number of investment projects increases the benefit from delegated monitoring of investment projects (Blackburn and Hung, 1998) or incentivizes market entry of financial intermediaries with positive cost effects due to specialization and competitiveness (Sussman, 1993). More generally, the positive relationship between capital accumulation and the demand for financial services goes back at least to Robinson (1952) who summarized the idea as "where enterprise leads, finance follows". Reviews on the theoretical and empirical literature are provided by Pagano (1993) and Levine (1997), respectively.[9]

While the cost function (9) has intuitively appealing features that are in line with the finance-growth literature, it bears implications for the financial stability effects of the net zero transition. The positive cross-derivative implies that capital management costs increase more strongly in response to deleveraging in the financial sector if the economy has accumulated a large amount of capital. Put differently, the capital demand function is steeper. The associated capital price drop is then more pronounced, thereby increasing the likelihood of systemic financial crises. Lastly, it is important to keep in mind that the (unobservable) empirical counterpart to capital management costs has to be corrected for secular trends, such as long term productivity or population growth. If this were not the case, the model would (counter-factually) predict a crisis probability close to zero fifty years ago, when the capital stock was much smaller. Instead, one should think about long term growth affecting the capital management costs in the same way as all macroeconomic aggregates.

Financial Intermediaries and Risk-Shifting Incentives Financial intermediaries convert their capital holdings into ω_t efficiency units, either using a safe or a risky technology. While the safe technology converts capital into one efficiency unit ($\omega_t = 1$), the risky technology is subject to idiosyncratic productivity shocks $\widetilde{\omega}$. The shock is i.i.d. over time and intermediaries and follows a log-normally distribution:

$$\log \widetilde{\omega}_t \overset{iid}{\sim} N\left(\frac{-\xi_t^2 - \psi}{2}, \xi_t\right) , \tag{11}$$

where $\psi < 1$. The good technology is superior as it has a higher mean and a lower variance due to $\psi < 1$ (see also Adrian and Shin, 2014 and Nuño and Thomas, 2017). The risky technology is characterized by higher upside risk due to the possibility of a large idiosyncratic shock realization $\widetilde{\omega}$. The volatility of idiosyncratic productivity shock ξ_t is an exogenous driver of financial cycles and an important trigger of financial crises in this model. In the spirit of Christiano et al. (2014), ξ_t is exogenous and follows an AR(1) process:

$$\xi_t = (1 - \rho^\xi)\xi + \rho^\xi \xi_{t-1} + \sigma^\xi \epsilon_t^\xi, \quad \text{where } \epsilon_t^\xi \sim N(0, 1) . \tag{12}$$

The intermediary earns the return $R_t^{K,j}$ which depends on the stochastic aggregate return R_t^K and (potentially) also on the realized idiosyncratic shock realization if the intermediary invested into the risky technology $\widetilde{\omega}_t^j R_t^K$. The aggregate return depends on the

[9] It is worth noting that writing the cost function in terms of household and total capital holdings $\mathcal{C}'(K_t^H, K_t)$ implies a negative partial derivative ($\frac{\partial \mathcal{C}'}{\partial K_t} < 0$) that reflects the idea that managing K_t^H units of capital is less costly to households in deep financial markets with plenty of investment opportunities, which allow for more portfolio diversification (Saint-Paul, 1992 or Acemoglu and Zilibotti, 1997).

price of capital Q_t and the profits per unit of capital $R_t^K = [(1-\delta)Q_t + Z_t]/Q_{t-1}$. The threshold realization $\overline{\omega}_t^j$ where the intermediary can exactly cover the face value of the deposits is given by

$$\overline{\omega}_t^j = \frac{\overline{R}_{t-1}^D D_{t-1}^j}{R_t^K Q_{t-1} K_{t-1}^{Bj}} \,. \tag{13}$$

Limited liability protects the intermediary in case of default, which distorts the intermediary's technology choice. The intermediary declares bankruptcy if the productivity shock realization is below $\overline{\omega}_t^j$. In this case, households seize the intermediaries' assets instead of receiving the promised deposit value. For this reason, the intermediary has an incentive to invest in the risky technology. Intermediaries profit fully from the upside risk, while limited liability eliminates the downside risk. The gain from limited liability for the risky technology is:

$$\Omega_t^j = \int_{-\infty}^{\overline{\omega}_{t+1}^j} (\overline{\omega}_{t+1}^j - \widetilde{\omega}) dF_t(\widetilde{\omega}) > 0. \tag{14}$$

In contrast, the gain from limited liability due to idiosyncratic risk is zero for the good technology. This creates a trade-off between the good technologies' higher mean return and the gains from limited liability for risky technology.

This results in a maximization problem, in which the financial intermediary maximizes the franchise value subject to an incentive and participation constraint. While we summarize the problem here, the complete derivation is relegated to Appendix A. The incentive constraint ensuring that intermediaries only invest in the good technology enters as an additional equilibrium condition:

$$(1-\pi_t)\mathbb{E}_t^N\left[\Lambda_{t,t+1}R_{t+1}^K(\theta\lambda_{t+1}^j+(1-\theta))\big(1-e^{\frac{-\psi}{2}}-\Omega_{t+1}^j\big)\right] = \pi_t\mathbb{E}_t^R\left[\Lambda_{t,t+1}R_{t+1}^K\big(e^{-\frac{\psi}{2}}-\overline{\omega}_{t+1}^j+\Omega_{t+1}^j\big)\right] . \tag{15}$$

where π_t is the probability of a run in period $t+1$. The expectation operators $\mathbb{E}_t^N[\cdot]$ and $\mathbb{E}_t^R[\cdot]$ are conditioned on the absence of a run and the occurrence of a run in period $t+1$, respectively. The trade-off between a higher mean return $(1-e^{\frac{-\psi}{2}})$ and the upside risk Ω_{t+1}^j can be seen on the LHS. In the case of a run, there is an additional gain of investing in the risky technology, as displayed on the RHS. The risky technology offers the possibility of having positive net worth despite a run if the idiosyncratic shock exceeds $\widetilde{\omega}_t^i > \overline{\omega}_t$.

λ_t^j on the LHS of eq. (15) is the multiplier on intermediaries' participation constraint, which we derive next. The return on deposits needs to be sufficient such that households are willing to provide deposits to intermediaries. While households earn the predetermined interest rate $\overline{R}_t^D$ in normal times, households recover the gross return on capital if a run occurs. As the return on deposits in a run is lower, an increase in the run probability π_t increases intermediaries' funding costs. The participation constraint can be written as:

$$(1-\pi_t)\mathbb{E}_t^N\left[\beta\Lambda_{t,t+1}\overline{R}_t^D D_t^j\right] + \pi_t\mathbb{E}_t^R\left[\beta\Lambda_{t,t+1}R_{t+1}^K Q_t K_t^{Bj}\right] = D_t^j\ . \tag{16}$$

Note that it turns out that the incentive constraint and the participation constraint do not depend on intermediary j specific values, so we can drop the subscript j. Thus, we can sum up over the intermediaries to obtain aggregate values.

Runs and Equilibrium Selection In our model, a systemic financial crisis corresponds to a state where households are unwilling to roll over deposits. Runs are self-fulfilling in the sense that households' expectations about a low liquidation value of financial intermediaries' assets induce them to withdraw deposits, which forces intermediaries to sell assets at fire sale prices, justifying households' expectations. The systemic nature of runs in our model is reflected by the idea that it destroys the entire net worth of the financial system, i.e., $N_{S,t}=0$. Newly entering intermediaries and households are the only agents left to acquire assets, which induces the price of capital to fall dramatically. We denote the fire sale price of capital by Q_t^* to determine whether a self-fulfilling run is supported and define the recovery ratio

$$x_{t+1}^* \equiv \frac{\big((1-\delta)Q_t^* + Z_t\big)K_{t-1}^B}{\overline{R}_{t-1}D_{t-1}}\ . \tag{17}$$

Runs are possible if $x_{t+1}^* < 1$ (Gertler and Kiyotaki, 2015). If the run equilibrium is possible, we select equilibria using a sunspot shock ϵ_t^π, following Cole and Kehoe (2000). The sunspot shock takes the value one with probability Υ and zero otherwise. The run probability follows as

$$\pi_t = \text{prob}(x_{t+1}^* < 1)\cdot\Upsilon\ . \tag{18}$$

Closing the model In the remaining part, we close the model by describing the retailers, the investment goods producers, the monetary policy, and the resource constraint.

Monopolistically competitive retail good firms buy the intermediate goods and transform them into a differentiated final good Y_t^j. Households' final good bundle Y_t, which is given by a CES-aggregate over all final goods varieties, and the price index are:

$$Y_t = \left[\int_0^1 (Y_t^j)^{\frac{\epsilon-1}{\epsilon}}dj\right]^{\frac{\epsilon}{\epsilon-1}}, \quad \text{and} \quad P_t = \left[\int_0^1 (P_t^j)^{1-\epsilon}dj\right]^{\frac{1}{1-\epsilon}}, \tag{19}$$

where the demand for the final good variety j negatively depends on its relative price:

$$Y_t^j = \left(P_t^j/P_t\right)^{-\epsilon} Y_t \ . \tag{20}$$

Retailers set prices to maximize profits subject to Rotemberg price adjustment costs:

$$\mathbb{E}_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \left[\Big(\frac{P_{t+s}^j}{P_{t+s}} - \overline{p}_{t+s} \Big) Y_{t+s}^j - \frac{\rho^r}{2} Y_{t+s}^j \Big(\frac{P_{t+s}^j}{\Pi P_{t+s-1}^j} - 1 \Big)^2 \right] , \tag{21}$$

where Π is the inflation target set by the central bank. Since their production function is linear in the intermediate good, retailers' marginal cost are simply given by the price of the intermediate good $MC_t = \overline{p}_t$. The New Keynesian Phillips curve follows as:

$$\left(\frac{\Pi_t}{\Pi} - 1 \right) \frac{\Pi_t}{\Pi} = \frac{\epsilon}{\rho^r} \Big(MC_t - \frac{\epsilon - 1}{\epsilon} \Big) + \Lambda_{t,t+1} \left(\frac{\Pi_{t+1}}{\Pi} - 1 \right) \frac{\Pi_{t+1}}{\Pi} \frac{Y_{t+1}}{Y_t} \ . \tag{22}$$

Investment good producers transform I_t units of the final good into $(a_1(I_t/K_{t-1})^{1-a_2}$ $+a_0)K_{t-1}$ units of the investment good, which they sell at price Q_t. Solving the maximization problem

$$\max_{I_t} \ Q_t \left(a_1 (I_t/K_{t-1})^{1-a_2} + a_0 \right) K_{t-1} - I_t \ , \tag{23}$$

yields an investment good supply function. The law of motion for capital is given by $K_t = (1-\delta)K_{t-1} + \Gamma\left(I_t/K_{t-1}\right) K_{t-1}$.

The monetary authority sets the interest rate R_t^I using a Taylor Rule subject to the zero lower bound:

$$R_t^I = \max \left\{ R^I \left(\frac{\Pi_t}{\Pi} \right)^{\kappa_\Pi} \left(\frac{MC_t}{MC} \right)^{\kappa_y} , 1 \right\} \ , \tag{24}$$

where deviations of marginal costs from its deterministic steady state MC reflect the output gap. To connect this rate to the household, there exists a one-period bond in zero net supply that pays the riskless nominal rate R_t^I. The associated Euler equation governs the pass-through from the monetary policy rate to the macroeconomy:

$$\mathbb{E}_t \left[\Lambda_{t,t+1} R_t^I / \Pi_{t+1} \right] = 1 \ . \tag{25}$$

The resource constraint includes the price adjustment and productivity losses from using the clean technology:

$$Y_t = C_t + I_t + G + \frac{\rho^r}{2} \Big(\frac{\Pi_t}{\Pi} - 1 \Big)^2 Y_t + \frac{b_1}{b_2 + 1} \left(\frac{\tau_t^c}{b_1} \right)^{\frac{b_2+1}{b_2}} Y_t \ , \tag{26}$$

where G is government spending.

3 Calibration and Solution

3.1 Parameter Choices

Each period corresponds to one quarter. We parameterize our model to match salient features of the macroeconomy, the financial sector, and climate policy. This results in a general calibration strategy that can easily adapted to potential country use cases. When we target specific non-climate related moments, we use the economy without a carbon tax, i.e. $\tau^c = 0$. An overview of the parameterization is given in Table 1.

Conventional parameters The discount factor β is chosen to account for an average risk-free rate of 1.0% in the long run in an economy without carbon taxes.[10] The labor supply curvature $\gamma_L = 4/3$ implies a Frisch labor elasticity of 0.75 following Chetty et al. (2011), while we use log utility for consumption ($\gamma^C = 1$). We normalize output via the long-run TFP level A and target a government spending-to-output ratio of 20%. The capital share α is set to 0.33 and the deprecation rate δ to 0.025. The Rotemberg pricing parameter ρ^r is set to 178, implying a duration of 5 quarters in the related Calvo framework. The investment adjustment cost parameters a_0 and a_1 are set to normalize the asset price and investment output. The curvature of the investment adjustment cost parameter is set in line with Bernanke et al. (1999). The central bank targets an inflation rate of 2%, while the response to the output gap $\kappa_y = 0.125$ and inflation $\kappa_\pi = 2.0$ are set to conventional choices.

Climate block The parameters related to the climate policy block of the model are set to match key properties of carbon emissions and the macroeconomic impact of carbon taxes. We exploit that the cost of adapting and operating the clean technology map directly in to the abatement cost function used in the DICE model of Nordhaus (2008). Its curvature is set to $b_2 = 1.6$ and the slope to $b_1 = 0.05$, which is in line with Heutel (2012).[11].

Since the carbon tax is expressed in abstract model units, which are hard to interpret, we transform the tax rate into carbon prices, i.e., dollars per unit of emissions. We follow the literature (Ferrari and Nispi Landi, 2023) and relate model-implied output y_t and emissions e_t in the initial stationary distribution to current world GDP (y^{world} = 105 trillion USD at PPP in 2023) and current global carbon emissions (e^{world} = 37.5 GtCO2 in 2023), respectively. Since output and emissions are normalized to one in the

[10] Carbon taxes have a negligible effect on the risk-free rate in this model.

[11] As the these parameters are subject to considerable uncertainty, we consider alternative values for robustness in Section 5.3

initial stationary distribution, the carbon price in dollars per tonne of carbon (\$/tCO2) associated with a given tax τ_t^c is then given by $p_t^c = \frac{y^{\text{world}}}{e^{\text{world}}}\tau_t^c$. Under our baseline value for b_1, we obtain a net zero tax of $\tau_t^c = 0.05$ from (1). This corresponds to a carbon price of 140\$/tCO2.[12]

As a next step, we need to parameterize the impact of emissions on temperature and economic losses. The impact of cumulative carbon emissions on temperature changes relative to pre-industrial levels is captured by the parameter Ψ_{CCR}. Empirically, this parameter lies in the range of $0.27° - 0.63°$ per 1,000 GtCO2 emitted (Fernandez-Villaverde et al., 2024). We pick $\Psi_{CCR} = 0.58°$ to reconcile the global temperature increases since pre-industrial levels: cumulated global emissions currently amount to $E_{2024Q4} =$ 2.400 GtCO2, such that we can back out the empirically observed temperature increase $\Delta\mathcal{T}_t = \Psi_{CCR} \cdot \frac{2400}{1000} = 1.4$°C for 2024. To put these numbers into perspective, note that in the adverse scenario with constant emissions after 2025, cumulated emissions in 2100 would amount to 5.100 GtCO2, implying a global temperature increase of 3.0°.

To map global temperature increases into economic damages, we draw on recent empirical work by Nath et al. (2024) and express GDP losses as $\Delta Y_t = -\gamma_T \Delta\mathcal{T}_t$. Using temperature shocks at the country level, Nath et al. (2024) estimate that a global temperature increase by $\Delta\mathcal{T}_t = 3.7°$ by 2100 is associated with a GDP loss of 7-12%. Using the mid-point of 9.5%, this implies a GDP loss of $\gamma_T = 2.5\%$ for each degree of global warming.[13] We obtain $\gamma_D = 0.0115$ for the quadratic utility loss function associated with global temperature increases in (8).[14]

Financial sector parameters The financial sector parameters are set to target salient features of financial cycles and systemic financial crises. We target an intermediary asset share of 1/3, implying that one-third of securities are funded by runnable deposits. For this reason, we set the target share of the household's asset holdings to $\gamma^F = 0.38$.

[12]While this tax appears quite small compared to currently observed emission permit prices in the EU emission trading scheme, it has to be noted that *all* emissions are taxed in our macroeconomic model. In contrast, only a limited share of emissions is subject to emission trading or carbon taxes and firms receive a considerable amount of free allowances in practice.

[13]Caggese et al. (2024) combine firm-level data with granular temperature shocks and estimate that a Paris-aligned warming scenario of $2°C$ induces a GDP loss of around 1.7%, which is in line with the lower bound of the effect size in Nath et al. (2024). In contrast, Bilal and Rossi-Hansberg (2023) estimate a welfare loss of 11.6% for a global temperature increase of $3°C$ by 2100, which would be at the upper bound of the estimates by Nath et al. (2024).

[14]Formally, the loss parameter $\gamma_D = 0.0115$ in the period utility function can be backed out using the following relationship:

$$\mathbb{E}_T\left[\beta^{T+t}u\Big((1-\gamma_T\cdot\Delta\mathcal{T}_t)C_t,\cdot,\Delta\mathcal{T}_t = 3°C;\gamma_D = 0\Big)\right] = \mathbb{E}_T\left[\beta^{T+t}\Big(C_t,\cdot,\Delta\mathcal{T}_t = 3°C;\gamma_D > 0\Big)\right],$$

where we set $T = 2100$ and all arguments entering household welfare evaluated under the adverse scenario of maintaining current policies indefinitely and taking into account the non-linear dynamics of the model. We focus on a temperature increase by $3°C$ since the, the model-implied temperature increase by 2100 corresponds to $3°C$ without further climate policy, see Figure 2.

The leverage of the financial intermediaries is set to 15, in line with equity to capital holdings in the financial sector of 6.67%. This value is obtained by setting households' intermediation cost to $\omega_F = 0.045$. The parameter controlling the mean return of the risky of technology follows Rottner (2023). The intermediary survival probability is set to a rather low value of $\zeta = 0.885$, which is helpful to incorporate runs in this type of model and is in line with the credit spread of 90 basis points over the risk-free rate (Gertler and Kiyotaki, 2015). The parameter that governs the initial endowment to new intermediaries is implied by the other parameters of the model. We set the standard deviation of our risk shock to match an annual run frequency of 2%, a value that is well in line with the evidence on financial crises in the macrohistory database of Jordà et al. (2017). The persistence of the shock follows Rottner (2023). The probability governing the sunspot shock is normalized to $\Upsilon = 0.5$, so that we attribute to both equilibria the same likelihood, conditional on their existence. The model's fit to the data is presented in Table B.1.

3.2 Global Solution Method

We solve the model using global solution methods. This is paramount to capture the nonlinear effects of financial crises on the macroeconomy and to allow for non-monotonic impacts of climate policy on the likelihood of financial crises. Specifically, we use time iteration with linear interpolation on a discretized state space. The model has two endogenous state variables, total capital K_t and financial sector net worth N_t, and two exogenous states, the risk shock ϵ_t^{ξ} and sunspot shock ϵ_t^{π}.

Transition paths are solved by backward induction starting from the terminal long-run equilibrium with net zero emissions. While the initial change in the transition speed is an unexpected shock, we account for uncertainty along the transition path as agents are aware of the materialization of shocks. Our solution method allows us to solve the equilibrium for any imposed carbon tax path. We refer to Appendix B for details on the numerical solution method.

4 Quantitative Analysis

In this section, we use our calibrated model to study the financial stability implications of climate policy, proceeding in three steps. First, we demonstrate how carbon taxes improve financial stability in the long-run. Second, we study the transition dynamics from the current climate policy trajectory onto a carbon tax path, which is consistent with emission reduction goals specified in the Paris Agreement. Third, we evaluate the net financial stability effect of such a climate policy shift. Fourth, we benchmark the welfare effects of "Climate Minsky Moments" against real costs and benefits of the net

Table 1: Calibration

a) Conventional parameters		Value	Target / Source
Discount factor	β	0.9975	Risk free rate of 1.0% p.a.
Frisch labor elasticity	$1/\gamma_L$	0.75	Chetty et al. (2011)
Risk aversion	γ_C	1	Log utility for consumption
TFP level	A	0.407	Output normalization
Government spending	G	0.2	Govt. spending to output ratio of 20%
Capital share	α	0.33	Capital income share of 33%
Capital depreciation	δ	0.025	Depreciation rate of 10% p.a.
Price elasticity of demand	ϵ	10	Markup of 11%
Rotemberg adjustment costs	ρ^r	178	Calvo duration of 5 quarters
Investment cost intercept	a_0	-.008	Normalization of $\Gamma(I/K) = I$
Investment cost slope	a_1	0.530	Asset price normalized to 1
Investment cost curvature	a_2	0.25	Bernanke et al. (1999)
Target inflation	Π	1.005	Inflation target of 2%
MP response to inflation	κ_Π	2.0	Conventional value
MP response to output	κ_y	0.125	Conventional value
b) Climate parameters		**Value**	**Target / Source**
Clean technology cost slope	b_1	0.05	In line with Nordhaus (2008)
Clean technology cost curvature	b_2	1.6	In line with Nordhaus (2008)
Temperature response	Ψ_{CCR}	$0.58°C$	Fernandez-Villaverde et al. (2024)
GDP loss	τ_T	0.077	In line with Nath et al. (2024)
Temperature loss	γ_D	0.0115	In line with Nath et al. (2024)
c) Financial sector and shock parameters		**Value**	**Target / Source**
Slope intermediation cost HH	γ^F	0.38	Share financial sector
Target intermediation cost HH	ω_F	0.0464	Leverage multiple of 15
Mean risky technology	ψ	0.01	Rottner (2023)
Survival rate	ζ	0.885	Credit spread of 90bp
Persistence risk	ρ^ξ	0.96	Rottner (2023)
Std. dev. risk shock	σ^ξ	0.0031	Financial crisis probability = 2%
Sunspot shock probability	Υ	0.5	Normalization

zero transition.

4.1 Carbon Taxes: Long-Run Effects

Figure 1 demonstrates how varying carbon taxes affect the macroeconomy and financial stability in the long-run. We solve the model economy for different time-invariant carbon tax levels, ranging from zero to 140\$/tCO2, which implies net zero emissions in our baseline calibration. The upper left panel shows the share of firms operating the clean technology for a given long-run carbon tax. The dashed red line indicates a value of 26\$/tCO2. This tax implies $\eta_t^* = 0.22$, corresponding to the empirically observed global emission intensity reduction by 33% from 1990 to 2023.

The bottom left panel shows that productivity losses increase in a convex fashion

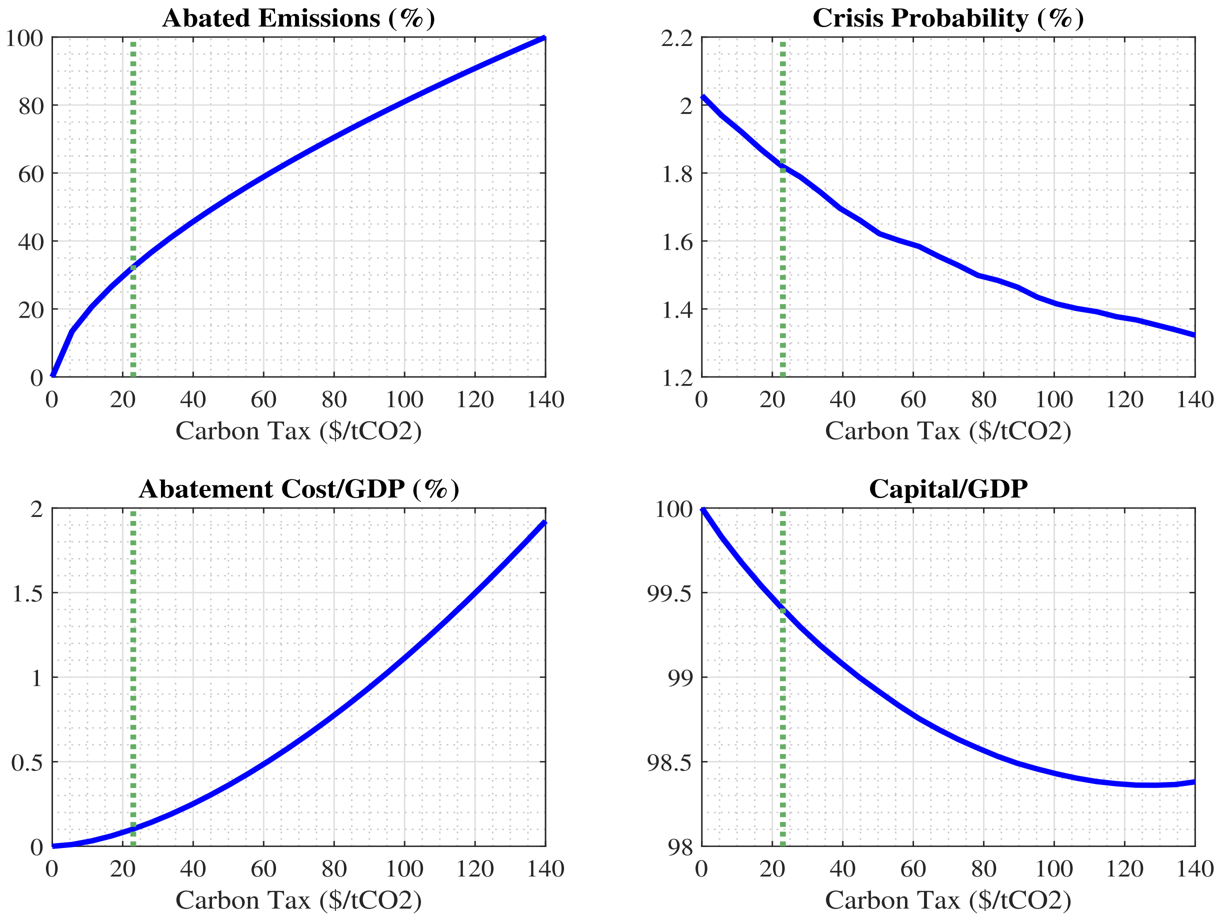

Figure 1: Carbon taxes and financial stability in the long-run. The impact of varying carbon taxes on abated emissions, the annualized crisis probability, productivity losses relative to GDP, and the capital/GDP ratio. The capital/GDP ratio is indexed to 100 for the case without carbon taxes. The green dotted line indicates the status quo carbon tax of 2023. The results are based on simulating the model for 100,000 periods with a burn-in of 10,000 periods.

towards net zero. In the bottom right panel, we demonstrate that higher carbon taxes are associated with less capital accumulation as measured by the capital/GDP ratio. For taxes exceeding 100 $/tCO2, this ratio is around 1.5% smaller than in the long run equilibrium without carbon taxes.

The top right panel of Figure 1 reveals that the annualized crisis probability declines from around 2% to around 1.4% under the 140%/tCO2 tax consistent with net zero. It has to be stressed that the positive effect on financial stability does *not* follow from a reduction in emission damages from which we abstract in the analysis for the moment. Instead, they stem from an equilibrium effect operating through capital accumulation and the relative size of the financial sector. Since carbon taxes reduce the average productivity of the economy, aggregate capital is smaller in the long-run, see the bottom right panel. Consequently, households must manage fewer assets and incur a smaller utility loss.

A lower demand for financial intermediation services depresses the crisis probability in the long-run: households have to acquire less capital if financial intermediaries need to sell assets to reduce their leverage ratio. It follows from their period utility function

(8) that they are willing to pay a higher price for holding capital, ceteris paribus. Thus, intermediaries are more likely to be able to service depositors even at the fire sale price. This reduces the partition of the state space supporting the run equilibrium, thereby reducing the run frequency.

4.2 Financial Stability Along the Transition to Net Zero

We now evaluate the impact of carbon taxes on financial stability during the net zero transition. We consider different carbon tax paths $\{\tau_{t+i}^{c,j}\}_{i=0}^{\infty}$, where the second superscript j indicates the path. Specifically, we consider an unanticipated shift from lenient *current trajectory* to a stringent *Paris-aligned* climate policy. There is no uncertainty about the carbon tax path, once it is revealed. In addition, we also report results for an unanticipated *policy freeze* that keeps carbon taxes at their 2024 level rather than following the *current trajectory*.

As a key reference point, the *current trajectory* is directly based on the historical decline in the global emission intensity. The emission intensity declined almost linearly over this period, and the average reduction relative to 1990 amounts to almost exactly one percentage point. The *current trajectory* simply extrapolates this emission reduction until net zero is reached, which would correspond to 2090. We compute the carbon tax path that gives rise to such a linear emission reduction by exploiting that the global emission intensity maps directly into the share of firms operating the clean technology (1). The implied carbon tax path is convex by the functional form assumption on the cost of operating the clean technology and is represented by the dashed black line in the upper left panel of Figure 2. We assume that the economy shifted from its long-run equilibrium without carbon taxes onto the *current trajectory* in 1990 - approximately coinciding with the Kyoto Protocol - which implies that the crisis probability is slightly above its 2% long-run level in 2025. In the following, we denote this path by $\{\tau_{t+i}^{c,current}\}_{i=0}^{\infty}$.

We then construct an ambitious carbon tax path that is aligned with the goals of the Paris Agreement. The carbon tax linearly increases until it is large enough to induce net zero emissions ($\eta_t^* = 1$) in $T_{max} = 2050$. We interpret the year 2025 as the initial period T_0 in which the economy unexpectedly shifts onto the *Paris-aligned* path. The solid blue line in the upper left panel of Figure 2 reflects this carbon tax path. The tax path exhibits an annual increase in carbon taxes by five percentage points relative to 2025 and will be denoted as $\{\tau_{t+i}^{c,Paris}\}_{i=0}^{\infty}$.

The next step is to evaluate the impact of these different transition paths on macroeconomic outcomes and financial stability, as measured by the crisis probability. An essential element in our analysis is that our framework is stochastic. To account for this, we simulate the economy along a given carbon tax path 100.000 times, where the risk shock and the sunspot shock are drawn randomly so that the volatility of idiosyncratic productivity

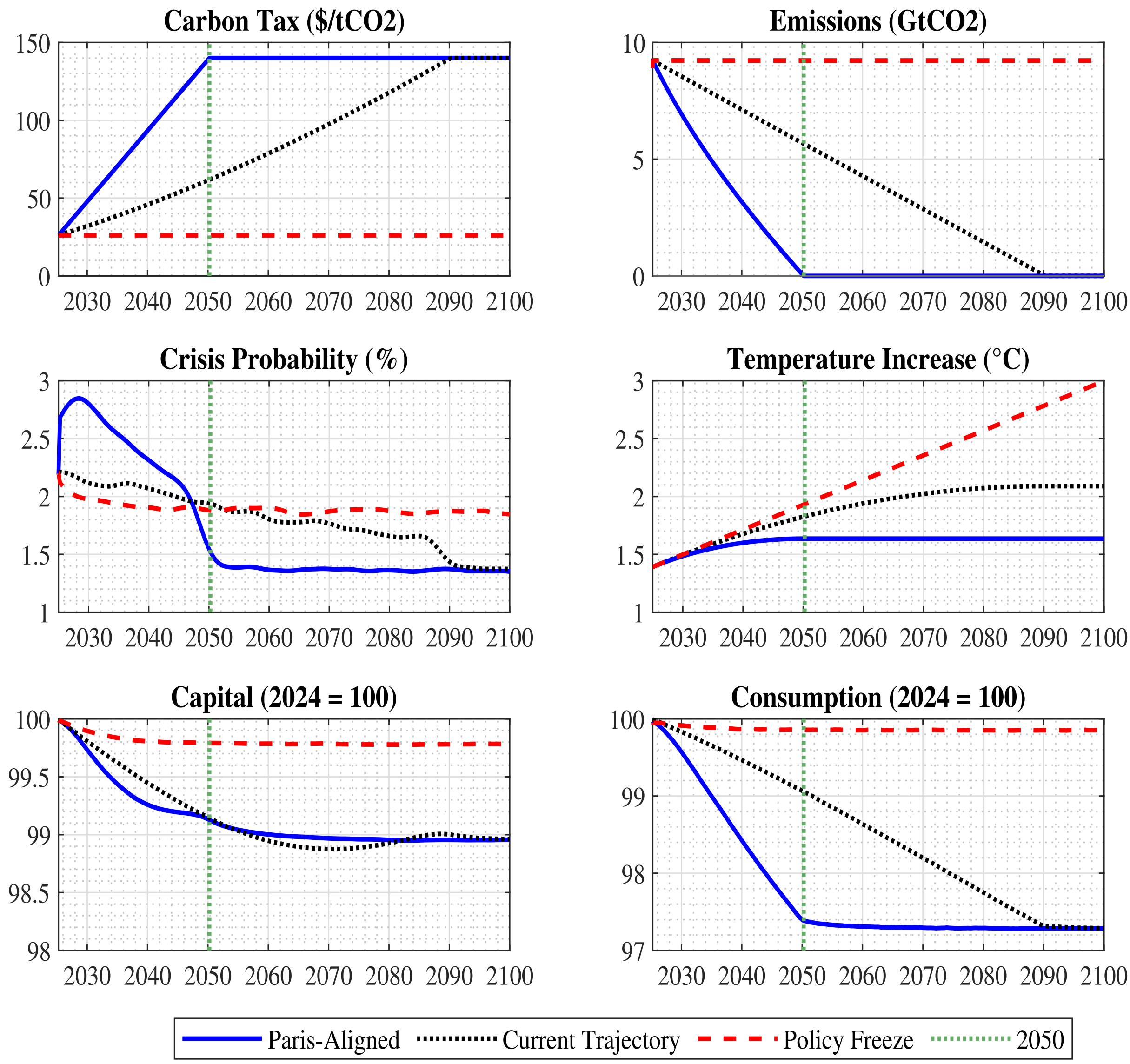

Figure 2: Transition path to net zero. Comparison of the impact of alternative transition paths - Paris-aligned, current trajectory, and policy freeze - on selected variables. The dynamics are shown for the years 2024Q4 until 2100Q4. The green dotted line indicates the year 2050. The results are based on simulating the model 100,000 times with a burn-in period of 200 quarters. Crisis probabilities are annualized, and cubic spline smoothing is applied to remove sampling error for improved readability.

shocks follows equation (12) and the sunspot shock selects the equilibrium if multiplicity is possible. We then average over all economies to calculate the crisis probability and other macroeconomic variables.[15]

The upper right panel of Figure 2 displays the implications of different carbon tax paths for carbon emissions. By construction, emissions reach zero under the *current trajectory* in 2090 and are zero thereafter. At each point in time, emissions are substantially smaller under the *Paris-aligned* path, while they are constant under the *policy freeze*. The right middle panel shows that the temperature goals of the Paris Agreement are missed under

[15] To enhance the readability of our graphs, we apply a cubic spline filter to the crisis probability. All numbers and moments are always computed based on the unfiltered simulation output.

the *policy freeze*, as the global temperature increases by around 3°C. On the *current trajectory*, the global temperature increases by slightly more than 2°C, which still exceeds the ambition of the Paris Agreement. In contrast, the ambitious transition manages to keep global warming at a manageable level. Consistent with the prediction from similar DSGE models, such as van der Ploeg and Rezai (2020), and recent empirical evidence (Kaenzig, 2023), a faster transition induces a stronger output contraction and larger asset return wedge ξ_t in the short-run. Therefore, consumption is inversely related to temperature outcomes in this model class, see the bottom right panel.

The left middle panel of Figure 2 shows the crisis probability along the transition. It increases from around 2.2% on the initial path to around 2.7% at the beginning of the *Paris-aligned* transition. At this point in time, the economy experiences an unanticipated shock to the carbon tax path and, thus, a negative permanent shock to the marginal product of capital. This event puts deleveraging pressure on the financial system. Notably, the crisis probability peaks several years into the transition and only slowly converges to its lower long-run level. Since capital and net worth are endogenous state variables, our model features a large degree of endogenous propagation. As the left middle panel of Figure 2 demonstrates, the crisis probability under the *Paris-aligned* transition path drops below the *current trajectory* in 2045. It stays below until net zero is reached on the *current trajectory* in 2090. Clearly, there is a net financial stability gain from a faster convergence to the new stationary long-run equilibrium. Consistent with the long run effect of carbon taxes on capital accumulation, the lower left panel demonstrates how aggregate capital declines along the transition. Appendix C additionally displays impulse response functions and the evolution of several key variables evolve during the transition, highlighting the outlined dynamics.

4.3 Net Financial Stability Effect

The next step is to evaluate the net financial stability effect of a carbon tax, which requires defining a suitable metric. Such a metric needs to take into account two crucial aspects. First, financial crises also occur in the absence of climate policy, so that an appropriate quantification of the threat of "Climate Minsky Moments" requires taking into account "Ordinary Minsky Moments" unrelated to ambitious carbon taxes. Second, since ambitious climate policy has a non-monotonic effect on the crisis probability along the transition, aggregating this effect over time is the key determinant of the net welfare effect.

To take these two aspects into account in a single metric, we define the *excess crisis* *probability (ExCP)*:

$$ExCP(\widetilde{\beta}) = \sum_{t=2025Q1}^{\infty} \widetilde{\beta}^t \left(\pi_t^{Paris} - \pi_t^{current} \right) , \tag{27}$$

where π_t^{Paris} is the probability of a financial crisis in period t on the tax path in line with the Paris Agreement and $\pi_t^{current}$ corresponds to crisis probability in period t on the *current trajectory*.

As stressed by Nordhaus (2007) and Weitzman (2007), social discounting is a crucial element in the evaluation of climate policies, which we capture by the parameter $\widetilde{\beta}$. While we do not take a stand on the appropriate social discount rate, the possibility of discounting future financial stability gains via the social discount factor puts different weights on the elevated crisis probability at the outset versus the long-run stability gains. Graphically, the *ExCP* is represented by the area between the crisis probability under the *Paris-aligned* path and the *current trajectory*, see the left panel of Figure 2. When the social discount factor is set to $\widetilde{\beta} = 1$, the excess crisis probability is obtained simply by subtracting the two areas.

The left panel of Figure 3 shows the *ExCP* for varying annualized social discount factors. The results highlight that the net financial stability effect depends on the social discount rate. If the discount rate is higher than 1.5 p.a., the *ExCP* is positive due to the increased fragility at the beginning of the transition. The *Paris-aligned* transition has then a negative financial stability effect. For social discount rates below 1.5% p.a., there is even a net positive financial stability effect. Thus, the emergence of a trade-off between climate policy and financial stability depends on the patience of the policy maker.

4.4 The Welfare Relevance of "Climate Minsky Moments"

Having discussed the net financial stability of climate policy and its ambiguous sign, we now turn to the key normative question of our paper: how important are "Climate Minsky Moments" in the general welfare assessment of climate policies? Social welfare is based on households' period utility function:

$$W_t(\{\tau_{t+i}^{c,j}\}_{i=0}^{\infty}) = \sum_{i=0}^{\infty} \widetilde{\beta}^i \mathbb{E}_t \left[\frac{(C_{t+i}^j)^{1-\gamma_C}}{1-\gamma_C} - \frac{(L_{t+i}^j)^{1+\gamma_L}}{1+\gamma_L} - \mathcal{C}(K_{t+i}^{H,j}, K_{t+i}^j) - \mathcal{D}(\Delta \mathcal{T}_{t+i}^j) \right] , \tag{28}$$

where the superscript j indicates the tax path and $\widetilde{\beta}$ is the social discount factor. The superscript j emphasizes that all equilibrium objects and welfare depend on the imposed carbon tax path $\{\tau_{t+i}^{c,j}\}_{i=0}^{\infty}$. The total welfare effect of a *Paris-aligned* policy is formally defined as

$$\Delta W_t^{total} = W_t\big(\{\tau_{t+i}^{c,Paris}\}_{i=0}^{\infty}\big) - W_t\big(\{\tau_{t+i}^{c,current}\}_{i=0}^{\infty}\big)\ . \tag{29}$$

where we compare welfare under the *Paris-aligned* path to the *current trajectory.*

It is straightforward to decompose the total welfare effect into a temperature gain component, a cost component reflecting productivity losses from adopting and operating clean technologies, and the macroeconomic costs of financial crises. Formally, $\Delta W_t^{total} = \Delta W_t^{temp} + \Delta W_t^{cost}$, where the welfare gain for temperate damages is given as the difference in the damage component in (8) under the different tax paths is given by

$$\Delta W_t^{temp} = \sum_{i=0}^{\infty} (\widetilde{\beta})^i \mathbb{E}_t \left[\mathcal{D}(\Delta\mathcal{T}_{t+i}(\tau_{t+i}^{c,Paris})) - \mathcal{D}(\Delta\mathcal{T}_{t+i}(\tau_{t+i}^{c,current}))\right]\ , \tag{30}$$

while the welfare costs from productivity losses and “Climate Minsky Moments” is given by

$$\Delta W_t^{cost} = \sum_{i=0}^{\infty} \widetilde{\beta}^i \mathbb{E}_t \left[\overline{u}(\tau_{t+i}^{c,Paris}) - \overline{u}(\tau_{t+i}^{c,current})\right]\ . \tag{31}$$

Here, $\overline{u}(\{\tau_{t+i}^{c,j})$ collects all elements of the household utility function (8) other than the losses from global warming, i.e., consumption, leisure, and capital management costs.

We isolate the welfare effect of “Climate Minsky Moments” from the overall costs of the net zero transition (31) by constructing a counterfactual that includes the *Paris-aligned* carbon tax path, but the run probabilities of the *current trajectory.* Formally, we subtract and add the utility from this counterfactual path $\overline{u}(\tau_{t+i}^{c,Paris})\big|_{\{\pi_{t+i}^{current}\}_{i=0}^{\infty}}$ to (31) to then decompose the welfare measure. The welfare costs of “Climate Minsky Moments” are the difference in utility that stems from the different run probabilities for the *Paris-aligned* path and *current trajectory.* Climate policy itself is fixed at the *Paris-aligned* path. Formally, this can be written as:

$$\Delta W_t^{Minsky} = \sum_{i=0}^{\infty} (\widetilde{\beta})^i \mathbb{E}_t \left[\overline{u}(\tau_{t+i}^{c,Paris})\big|_{\{\pi_{t+i}^{Paris}\}_{i=0}^{\infty}} - \overline{u}(\tau_{t+i}^{c,Paris})\big|_{\{\pi_{t+i}^{current}\}_{i=0}^{\infty}}\right]\ . \tag{32}$$

Note that we define, for consistency, $\overline{u}(\tau_{t+i}^{c,Paris}) \equiv \overline{u}(\tau_{t+i}^{c,Paris})\big|_{\{\pi_{t+i}^{Paris}\}_{i=0}^{\infty}}$. This formulation highlights that the tax path and the run probabilities come both from the same *Paris-aligned* transition.

The welfare losses from productivity losses are then given by the difference between

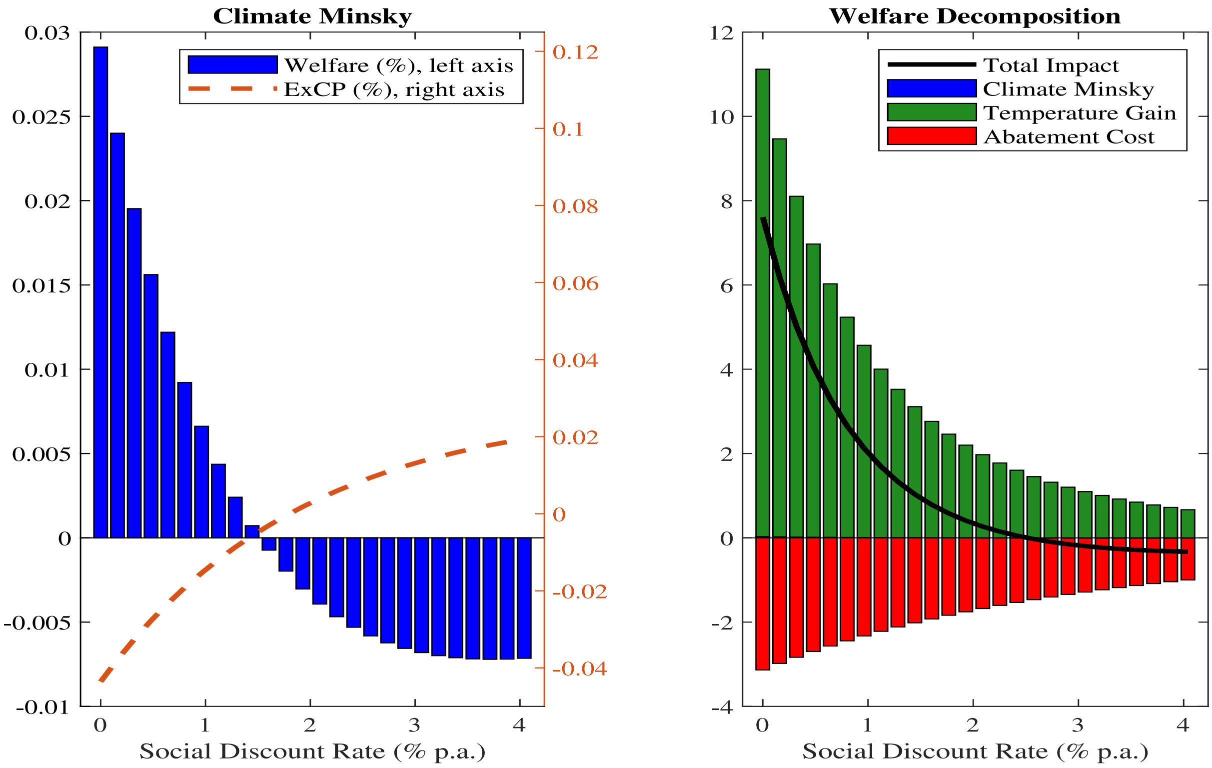

Figure 3: Welfare and financial stability effects. Left panel: Welfare effect of "Climate Minsky Moments" (left axis) and the excess crisis probability for varying social discount rates. Right panel: Decomposition of total welfare into contributions from "Climate Minsky Moments", temperature gains, and productivity losses. The results are based on 100,000 model simulations with a burn-in period of 200 quarters.

the two tax paths, in which the run probability is kept constant at the *current trajectory*:

$$\Delta W_t^{prod} = \sum_{i=0}^{\infty} (\widetilde{\beta})^i \mathbb{E}_t \left[\overline{u}(\tau_{t+i}^{c,Paris})\big|_{\{\pi_{t+i}^{current}\}_{i=0}^{\infty}} - \overline{u}(\tau_{t+i}^{c,current})\big|_{\{\pi_{t+i}^{current}\}_{i=0}^{\infty}} \right] . \tag{33}$$

It is worth noting that "Climate Minsky Moments" also affect the welfare losses from global warming. Financial crises are associated with deep and long-lasting recessions that somewhat mitigate global warming. However, this effect is quantitatively negligible, so we base our welfare measure of "Climate Minsky Moments" solely on the cost component.

The left panel of Figure 3 displays the welfare effect of "Climate Minsky Moments" as blue bars in consumption equivalents. They generally have the inverse shape of the *ExCP*, as a larger crisis probability is associated with welfare losses. Excess crisis probability and welfare change sign for a social discount rate of around 1.5%.

The right panel of Figure 3 shows that the threat of "Climate Minsky Moments" does not substantially affect the basic climate policy trade-off between productivity losses associated with stringent carbon taxes (red bars) and gains from a reduction of global surface temperatures (green bars). Note that the figure does, in fact, feature the welfare effect of "Climate Minsky Moments" as blue bars, but they are barely visible due to its considerably smaller scale. The welfare gains from curbing global warming amount to approximately 11% in consumption equivalents for a social discount rate near zero, greatly exceeding the productivity losses from the clean technology (around 3%). As the social discount rate increases, temperature gains rapidly lose relevance. At a social discount rate of around 1.5% the net effect turns negative.

The threat of "Climate Minsky Moments" does not substantially affect whether this trade-off is resolved in favor or against ambitious climate policy. Taken together, our analysis suggests that changed financial fragility provides net welfare gains if policymakers are very patient. For high social discount rates, they inflict a slight welfare loss that amounts to less than one percent of the total losses associated with the transition to emission-free technologies.

5 Model Extensions and Climate Policy Variations

As a next step, we want to explore the sensitivity of our welfare assessment. For this reason, we provide a large set of modifications for the production sector, the climate block, and the specifications of climate policy. Our analysis demonstrates the robustness of our result about the welfare (ir)relevance of "Climate Minsky Moments".

Our different modifications can be broadly categorized as i) model extensions, ii) variations in climate policy, and iii) parameter sensitivity analysis. Specifically, we evaluate four model extensions: the introduction of physical risk, technological change directed at emission reduction activities, trend growth, and various modifications to the production sector, such as a clean-dirty two-sector production function. Regarding the policy path for our Paris-aligned transition, we consider an alternative fiscal policy that uses the income generated from the carbon tax to subsidize clean technology adoption, a change in the year at which net zero is reached, and modifications in the shape of the transition path. Finally, we vary the productivity loss parameters and the welfare costs stemming from global warming.

Table 2 summarizes our results from most of the different alternations. The table compares our key metrics across the different modifications: the maximum difference between crisis probabilities between the Paris-aligned and the current trajectory (column 1), the long-run crisis probability (column 2), excess crisis probability (column 3), welfare effect of Climate Minsky Moments (column 4), the welfare costs of productivity losses (column 5) and the welfare gain due to emission reduction (column 6), which is directly related to the temperature change (column 7).

The key takeaway is that initially, the crisis probability increases, even though the peak effect varies slightly across modifications. In the long-run, there is a reduction relative to a world without carbon taxes (and climate damages). The effects seem to rather balance out for the set of plausible rates, as shown by a value of the excess crisis probability close to zero. Importantly, our finding that the welfare effect of "Climate Minsky Moments" is

Table 2: Financial stability, climate, and welfare outcomes for various modifications

	Max Δ crisis pr. %[a]	Long-run crisis pr. %[b]	Excess crisis pr. %[c]	Welfare Minsky CE %[d]	Welfare prod. CE %[e]	Welfare temp. CE %[f]	Temp. change °C[g]
Baseline model	0.91	1.36	-0.01	0.005	-2.30	4.41	1.63
Climate block extensions							
Physical risk	0.36	0.70	0.03	-0.017	Net: 2.01[h]		1.59
Technological change	1.21	2.09	-0.01	0.001	-1.42	7.25	1.53
Trend growth	0.94	1.36	-0.01	0.005	-2.30	5.89	1.66
Climate policy variations							
Clean technology subsidies	0.91	1.36	0.01	-0.006	-2.12	5.28	1.64
Net zero in 2045	1.24	1.36	-0.01	0.004	-2.59	4.91	1.59
Net zero in 2055	0.82	1.36	-0.01	0.007	-2.02	3.92	1.68
Front-loaded transition	1.62	1.36	-0.01	0.007	-2.63	5.06	1.57
Back-loaded transition	0.90	1.36	-0.01	0.001	-1.99	3.69	1.70
Climate parameter sensitivity analysis							
High productivity losses	0.95	1.24	-0.011	0.005	-2.77	4.40	1.63
Low climate damages	0.91	1.36	-0.01	0.005	-2.30	3.24	1.63
High climate damages	0.91	1.36	-0.01	0.005	-2.30	5.67	1.63

[a] Maximum difference between (annualized) financial crisis probability $\pi_t^{Paris} - \pi_t^{current}$.
[b] Long-run financial crisis probability (annualized) in terminal net zero equilibrium.
[c] Excess crisis probability (ExCP) computed for $\widetilde{\beta} = 0.9975$.
[d] Welfare effect of Climate Minsky Moments in consumption equivalent with $\widetilde{\beta} = 0.9975$.
[e] Welfare effect due to productivity losses in consumption equivalent $\widetilde{\beta} = 0.9975$.
[f] Welfare effect due to temperature in consumption equivalent $\widetilde{\beta} = 0.9975$.
[g] Temperature change relative to its pre-industrial level in 1850 expressed in degree Celsius.
[h] The net welfare effect for physical risk is reported to avoid altering the decomposition.

clearly second-order also holds across all specifications. While there are some substantial changes in the welfare effects from curbing climate change in the different modifications, the relative ranking concerning financial stability is clearly untouched.

5.1 Extending the Climate Block

Physical Risk In our baseline model, damages associated with global warming affect welfare directly through the household utility function. Capturing the welfare benefit of ambitious climate policy in this way is quite common in the literature. It constitutes a tractable alternative to a damage function that negatively affects aggregate TFP. In this paragraph, we show that our results are robust to including climate change damages directly in the aggregate production function. This alternative formulation is then given by

$$Y_t = \exp(-\gamma_T \Delta \mathcal{T}_t) A K_{t-1}^{\alpha} L_t^{1-\alpha} \ . \tag{34}$$

Consequently, we drop the utility losses from temperature increases incurred by households. The parameter γ_T is informed directly from recent empirical work by Nath et al. (2024). Note that in these extensions, cumulated emissions become an additional endogenous state variable, which we take into account in the numerical solution method. Besides the computational costs of adding an endogenous state variable to the model, physical risk also complicates the welfare decomposition into a temperature and a cost component. Therefore, we report only the net welfare effect in Table 2, which turns out to be very similar to the baseline model. The long-run crisis probability under the Paris-aligned transition is smaller than in the baseline, as climate damages through physical risk further depress productivity and, thereby, the demand for financial services and the size of the financial sector. As in the baseline model, Climate Minsky Moments are a negligible component of aggregate welfare.

Directed Technological Change So far, we have assumed that the cost of operating clean technologies are constant over time. However, technological change directed toward emission-reduction technologies could reduce the costs of operating clean technologies permanently. We incorporate this concept in our framework by assuming that the cost parameter b_1 declines linearly over time from the starting value $b_{1,1990} = 0.06$ in 1990 to $b_{1,2090} = 0$ in the long-run, i.e. after net zero is reached on the *current trajectory* in 2090. Notably, the *Paris-aligned* linear tax path actually achieves net zero slightly earlier under technological change and the productivity losses from operating the clean technology vanish in the long run.

While temperature increases are generally more modest in this extension, the time path of the initial crisis probability is very similar to the baseline model. An important difference is that the crisis probability in the long-run equilibrium with net zero taxes corresponds to the crisis probability in the initial equilibrium absent climate policy. The excess crisis probability is, therefore, slightly larger than in the baseline. However, this modification also does not affect the second-order role of financial stability relative to the welfare implications of curbing global warming.

Trend Growth in Emissions Our model, including its climate block, is expressed in terms variables that are adjusted for secular trends in population and productivity growth, which is common practice in macroeconomic modelling. However, one can argue that climate damages depend on cumulated actual emissions, rather than on cumulated emissions adjusted for long run productivity growth. This would be the case if, for example, adaptation to global warming is not feasible in some regions. In this extension, we allow for trend growth in emissions of one percent p.a., which substantially amplifies the positive effects of ambitious climate policy. For instance, global temperatures would increase by more than 5° under the *policy freeze* in this extension, which is in line with the pessimistic scenarios published by the IPCC. Consequently, it becomes more costly in terms of global temperatures to miss net zero goals in future periods with a larger economy. As the crisis probability is unaffected, the welfare relevance of “Climate Minsky Moments” is slightly diminished.

Alternative Production Functions Our baseline model connects carbon taxes with emission reduction activities by adding a simple technology choice problem to the firm sector. A key implication of this model is that higher carbon taxes drive a wedge in the return on aggregate capital, such that the economy accumulates less capital. In Appendix D.1, we demonstrate that this negative relationship between carbon taxes and capital accumulation also arises in other models commonly used in the assessment of climate policies. Specifically, we consider variations where a) emissions are only associated with the use of capital, b) energy is a production input and subject to carbon taxes but can be produced in a dirty or clean way, and c) there are two production technologies, a ”clean” and a ”dirty” one but firms are not able to switch between them. The last model abstracts from technological choice and carbon taxes but induces a reallocation of capital from the dirty to the clean sector. Under conventional assumptions on aggregate production functions, such a re-allocation also reduces aggregate capital accumulation.

5.2 Alternative Climate Policy Specifications

Fiscal Subsidies We examine the role of fiscal policy and allow for the possibility of clean technology subsidies through the lens of our model. So far, we assumed that carbon tax revenues are rebated to households in a lump sum fashion. Now, the carbon tax revenue is used to subsidize firms' adoption of clean technologies.[16] Specifically, firms receive a flat subsidy per abated unit of emissions $\eta_t Y_t$, which is financed with carbon tax revenues. From the minimization problem, as shown in detail in Appendix Appendix D.2, we can see that the share of clean firms exceeds the share in the baseline model for any given carbon tax below net zero. Furthermore, the associated wedge in the return on capital is smaller than under the assumption of tax rebates to households.

[16]While climate policy has usually focused on carbon pricing and R&D subsidies for emission-free technologies, policymakers have recently started to subsidize the adoption of low-emission technologies at a large-scale. Examples include the ”Inflation Reduction Act” in the US and the European Commission's ”Green New Deal”. For an analysis of different fiscal policy regimes in the context of transition risk, see Carattini et al. (2024).

Such a policy substantially impacts the transition dynamics for the *Paris-aligned* tax path. The crisis probability increases very slowly over the first ten years of the transition. The subsidy cushions intermediary net worth against rapid drops in the return on their assets, which entails a financial stability gain at the outset of the transition. At the same time, this makes the downward adjustment of capital more sluggish. Therefore, the economy operates a larger capital stock well into the transition compared to the case without subsidies. Once tax revenues approach zero, the per-unit subsidy becomes small, and asset returns decline. Intermediaries face then increasing pressure to sell capital, which is still costly for households to absorb. The crisis probability, thus, remains above the *current trajectory* throughout the later stages of the transition. The long-run crisis probability is unchanged as there is no tax revenue once net zero is reached. Taking all together, this results in a *excess crisis probability* that is above the baseline scenario. Nevertheless, the benefits of reduced temperature increases outweigh their costs, as Table 2 highlights. Our analysis suggests that subsidies - a popular alternative policy instrument to accelerate the net zero transition - conflict to some extent with financial stability objectives. However, the climate policy trade-off is heavily solved in favor of subsidies due to their large positive effect on the adoption of clean technologies and the associated emission reduction.

Changing the Transition Speed While the Paris Agreement envisions a path to net zero until 2050, understanding the impact of deviating from the target is an important question. Specifically, we change the year at which net zero emissions are reached. While net zero is reached in 2050 in the baseline *Paris-aligned* transition path, net zero is achieved in the alternative transition scenarios either earlier ($T_{max} = 2045$) or later ($T_{max} = 2055$). Accelerating the transition has a clearly positive effect on curbing global warming. The difference amounts to around 0.1° by the end of the century. At the same time, the initial increase in instability is affected by the speed of the transition. With $T_{max} = 2045$, the peak would be to some extent larger as it increases slightly above 3% p.a. In contrast, a prolonged transition with $T_{max} = 2055$ implies a lower peak. However, the *excess crisis probability* in total is rather unaffected, as the crisis probability shrinks more slowly towards the new stationary equilibrium when net zero is reached in 2055. While the welfare effects are affected by an alternative target date, the second-order relevance of "Climate Minsky Moments" is unchanged.

Shape of the Transition: Front-Loaded versus Back-Loaded Path To take advantage of the medium-run financial stability gains without temporarily elevated crisis probabilities, it is reasonable to ask whether temporary delays of the transition yield superior net financial stability outcomes along the net zero transition. To ensure that such a delay does not come at the expense of climate policy objectives, such a temporary delay has to be accompanied by more aggressive carbon tax hikes at a later stage. This introduces a convexity into the carbon tax path. The back-loaded path features a rapid increase in the carbon tax in the last periods before reaching net zero. Such a scenario is sometimes referred to as a "disorderly transition." We also define a front-loaded transition path that adds the (time-varying) difference between the current trajectory and back-loaded taxes. The details are in Appendix D.3.

The shape of the tax path has a substantial impact on financial stability during the transition. A more aggressive path (front-loaded) is generally characterized by a lower crisis probability in the medium-run, which comes at the cost of considerable financial fragility during the first years of the transition. At the same time, a back-loaded transition does not yield an improved financial stability outcome. Instead, it spreads the elevated crisis probabilities over time, but as lower peak crisis probability in the short run. In both cases, the ExCP is quite similar to the baseline path and the net welfare effect is crucially shaped by the social discount rate and remains second-order in comparison to prodcuctivity losses and temperature gains.

5.3 Sensitivity Analysis: Climate Parameters

Productivity Losses One challenge in a quantification of the climate block is the uncertainty related to the key parameters, such as the productivity losses from using clean technologies (Friedl et al., 2023). For this reason, we choose a higher value to mitigate concerns that our baseline parameterization underestimates transition risks. If b_1 is larger, the policymaker needs to implement a larger carbon tax to induce net zero, which in turn has a stronger negative effect on asset returns and short-run crisis probabilities.

In our alternative specification, a tax of 170\$/tCO2 induces net zero, requiring steeper carbon tax path. This implies a peak crisis probability of close to 3% p.a. during the first years of the transition: "Climate Minsky Moments" are more relevant than under the baseline parameterization. At the same time, the medium run financial stability gains are also higher, since long-run productivity and capital also decline by more. Reaching the new long-run equilibrium faster is, thus, more beneficial than in the baseline parameterization. The changes in the excess crisis probability and the welfare change due to "Climate Minsky Moments" are minor. However, the welfare cost of switching technologies is now substantially higher so that the trade-off with temperature becomes even more prominent. Thus, the quantitative welfare relevance of "Climate Minsky Moments" amounts to an even smaller share for the welfare considerations.

Losses from Temperature Increases Another important dimension is how global temperature changes translate into losses to households. Since temperature losses enter the household utility function in an additive fashion, the effect of different climate policy trajectories on the macroeconomy and financial stability is independent of the parameter γ_D. Therefore, such a change in the costs affects only the welfare resulting from temperature damages.

Specifically, we use the effect bounds estimated by Nath et al. (2024) to back out a range of the utility damage parameters γ_D. The lower bound is a GDP loss of 1.9% for each degree of global warming, closer to the estimate by Caggese et al. (2024), while the upper bound is given by 3.2%, which is close to the estimate by Bilal and Rossi-Hansberg (2023). These estimates directly map into a high and low damage parameter $\gamma_D = \{0.0085, 0.0147\}$ in the household utility function. Note that this re-parameterization does not affect global temperature increases under different climate policies, but merely the utility loss they inflict. Since this variation does not affect the welfare effect of "Climate Minsky Moments", they remain relatively minor in comparison to the welfare impact of temperature changes, as Table 2 highlights.

6 Macroprudential and Monetary Policy

Our analysis has important implications for the interactions between climate policy and the conduct of macroprudential and monetary policies. We first show that the financial cycle is a crucial driver of the financial stability effects associated with stringent climate policies. We then discuss how monetary policy can help alleviate the negative financial stability effects of the transition. This turns out to depend critically on the shape of the climate policy path. Again, the endogeneity of the financial sector is key.

6.1 Macroprudential Policy: The Role of the Financial Cycle

The possibility of a "Climate Minsky Moment" depends jointly on the (exogenous) climate policy stance and the (endogenous) loss-absorbing capacity of the financial sector, i.e., its net worth. We illustrate how the loss-absorbing capacity shapes the financial stability implications of climate policy action. We focus on the same *Paris-aligned* transition path as before but condition our simulation on specific realizations of the risk shock, which endogenously affects the financial sectors' loss-absorbing capacity.

First, we consider a sequence of negative (one standard deviation) risk shock realizations in two quarters prior to the climate policy shift. This period of low volatility induces high leverage and a credit boom, capturing a volatility paradox in the spirit of Brunnermeier and Sannikov (2014). Once the surprise climate policy shift arrives, the financial sector is highly leveraged and lacks loss-absorbing capacity. As a consequence, the annualized crisis probability spikes to slightly more than 5% and stays elevated way into the transition. The dashed red line in the right panel of Figure 4 shows the run probability in the high-risk case.

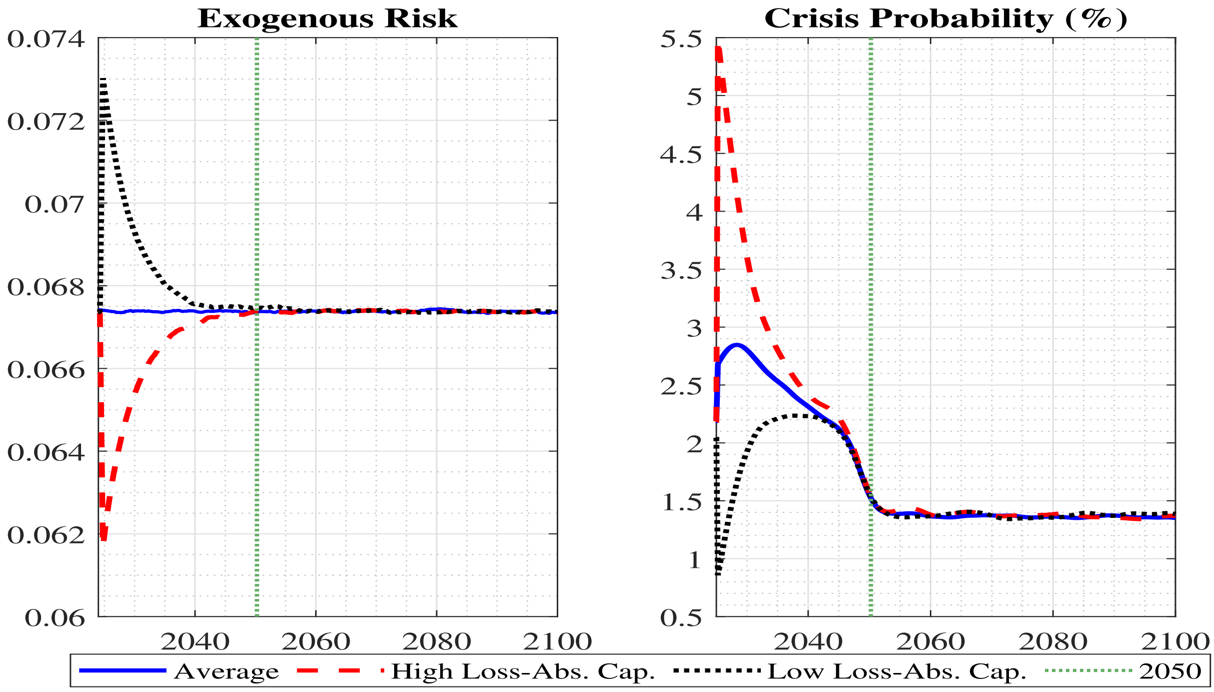

Figure 4: Role of the financial cycle. Impact of loss-absorbing capacity on the crisis probability (right panel). The low (high) loss-absorbing scenario assumes an additional risk shock realization of minus (plus) one standard deviation relative to the baseline scenario in the two quarters preceding the shift towards the Paris-aligned path, as shown in the left panel. The green dotted line indicates the year 2050. The results are based on simulating the model 100,000 times with a burn-in period of 200 quarters. Crisis probabilities are annualized, and cubic spline smoothing is applied to remove sampling error for improved readability.

The opposing path, that is a sequence of positive (one standard deviation) risk shock realizations, forces the financial sector to deleverage prior to the climate policy shift. When the shift arrives, the financial sector is much better equipped to accommodate the sudden productivity loss without selling securities at a fire sale price. The crisis probability, displayed as the dotted green line in the right panel of Figure 4, declines substantially. The crisis probability remains persistently low, as the capital accumulation channel of climate policy dominates in the medium-run. Appendix E contains additional results for the net financial stability effect and welfare.

This analysis outlines that a careful design of the transition to net zero should take vulnerabilities in the financial system into account. The threat of a "Climate Minsky Moment" after the climate policy shift depends to a substantial degree on the loss-absorbing capacity of the financial sector. The key implication for macroprudential policymakers is to ensure that the loss-absorbing capacity is large in order to facilitate a smooth transition to net zero. Our results point towards welfare gains from coordinating macroprudential and climate policies.

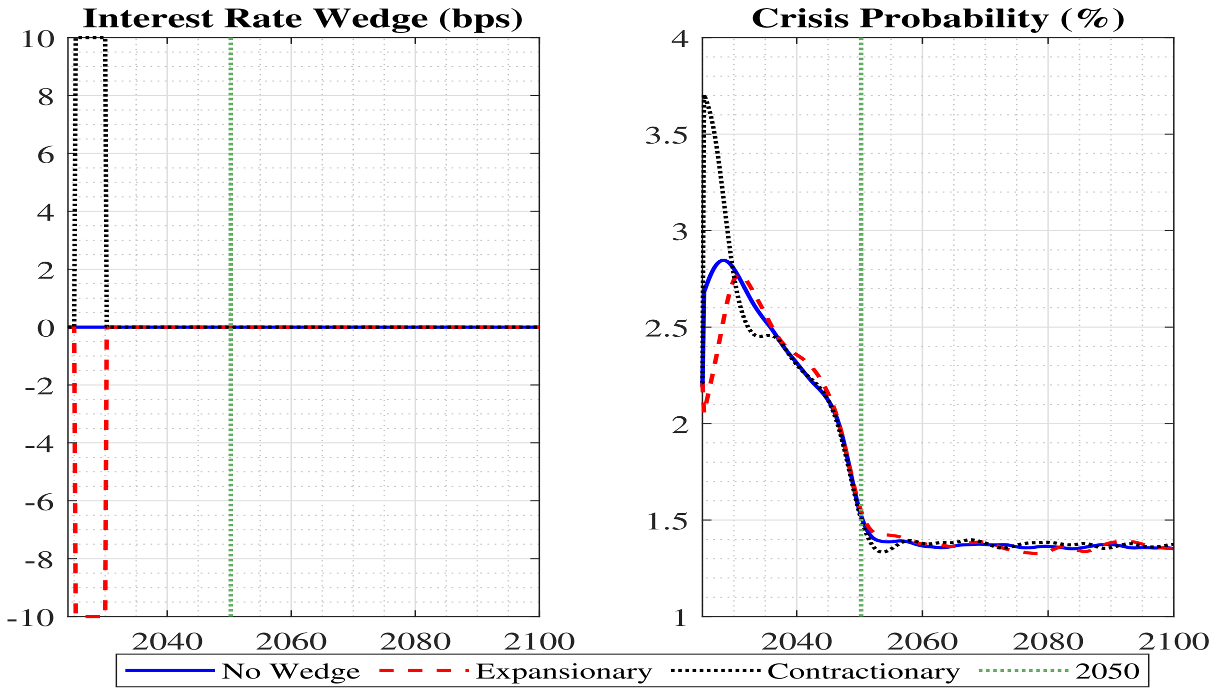

Figure 5: Role of the monetary policy stance. Impact of alternative monetary stances (left panel) on the crisis probability (right panel). The expansionary (contractionary) scenario assumes a negative (positive) wedge of 10 bps in each period in the first 5 years after the switch to the Paris-aligned path. The green dotted line indicates the year 2050. The results are based on simulating the model 100,000 times with a burn-in period of 200 quarters. Crisis probabilities are annualized, and cubic spline smoothing is applied to remove sampling error for improved readability.

6.2 Monetary Policy

The possibility of "Climate Minsky Moments" also has implications for monetary policy within central banks' financial stability mandates. Monetary policy can accommodate the transition by initially reducing nominal interest rates. This affects the probability of financial crises in two ambiguous ways: by increasing asset valuations, it reduces the partition of the state space supporting runs. On the other hand, this incentivizes intermediaries to increase their leverage, with negative effects on loss-absorbing capacities and elevated crisis probabilities in the future. Containing surges in the financial crisis probability by expansionary monetary policy has beneficial short-run effects, which come at a medium run cost.

Alternatively, monetary policy can lean against the transition. Here, an increase in policy rates at the onset of the transition initially amplifies run probabilities by further depressing asset prices. At the same time, this increases the loss-absorbing capacity going forward. In both cases, the net effect depends on deleveraging incentives that carbon taxes exert on intermediaries and social discounting.

We study how monetary policy affects the likelihood of "Climate Minsky Moments" when it accommodates or leans against the transition. Holding the climate policy path fixed, we add a linear forward guidance term i_t^{wedge} to the monetary policy rule (24):

$$R_t^I = \max\left\{ R^I \left(\frac{\Pi_t}{\Pi}\right)^{\kappa_\Pi} \left(\frac{MC_t}{MC}\right)^{\kappa_y} + i_t^{wedge}, 1 \right\} .$$

The (annualized) wedge is set to 10bps (contractionary) or -10bps (expansionary) for every quarter t in the first five years after the onset of the transition and to zero afterward, see the left panel of Figure 5. The right panel of Figure 5 shows that the crisis probability drops to around 1.8% (dashed red line) for expansionary monetary policy and then overshoots slightly before reverting back to its old path. The opposite pattern emerges for a contractionary forward guidance term. Our results imply that monetary should avoid a "leaning against the transition" approach to avoid increased instability. This is particularly relevant as the impact of the wedge is asymmetric. The contractionary stance has a relatively larger absolute effect on the crisis probability as it surges by one percentage point. An expansionary stance, instead, only lowers the crisis probability by approximately half a percentage point.

Does such a monetary policy adjustment mitigate the welfare effects of Climate Minsky Moments in a quantitatively meaningful way? To ensure a fair comparison between *Paris-aligned* transition paths and the *current trajectory*, we also solve and simulate the *current trajectory* under the modified monetary policy rule. Therefore, as shown in Appendix E, monetary policy does not materially affect the excess crisis probability, the welfare effects of Climate Minsky Moments, and the social discount rate at which they switch signs.

7 Conclusion

In this paper, we have shown that climate policy has non-trivial effects on financial stability. We propose, solve, and calibrate a nonlinear quantitative macroeconomic model with carbon taxes and endogenous financial crises and derive three main results. First, asset stranding decreases financial stability in the short-run when the economy moves unexpectedly onto an ambitious carbon tax path. In response to such a negative shock to the return on their assets, financial intermediaries face deleveraging pressure, which induces them to sell assets quickly, potentially at fire sale prices. This makes a systemic financial crisis more likely. Second, climate policy is not detrimental to financial stability in the long-run, since climate policy reduces long-run capital accumulation and, thereby, requires households to absorb fewer assets from the financial sector in an economic downturn. This softens the asset price drop in a downturn and makes systemic financial crises less likely.

Third, we show that the net effect of these opposing forces on financial stability and welfare crucially depends on the social discount rate. For a sufficiently patient policymaker, there is no trade-off between achieving climate policy goals and maintaining financial stability, since future stability gains receive a large welfare weight. If the social discount rate is high, a Paris-aligned transition implies welfare losses due to "Climate Minsky Moments". However, we demonstrate that the welfare losses associated with "Climate Minsky Moments" are at most second-order compared with the welfare cost of adopting clean technologies. This result is robust to a large set of reasonable modifications, such as model extensions of the climate block, variations in the specification of climate policy, and plausible parameter changes concerning climate change damages and productivity losses from using clean technologies. Our results suggest that financial stability concerns are not a valid reason to delay ambitious climate policy action.

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A Model Appendix

In this section, we outline the maximization problem of financial intermediaries, which follows Rottner (2023).[17] The financial intermediary j maximizes its franchise value V_t^j subject to an incentive constraint and a participation constraint. The incentive constraint ensures that the intermediary only invests in the good technology. The participation constraint ensures that the return on deposits is sufficient that households provide deposits to the intermediary. The maximization problem reads as follows:

$$V_t^j(N_t^j) = \max_{K_t^{Bj},\overline{D}_t} (1-\pi_t^j)\beta E_t^N \Lambda_{t,t+1}\left[\theta V_{t+1}^j\left(N_{t+1}^j\right) + (1-\theta)(R_{t+1}^K Q_t K_t^{Bj} - \overline{D}_t^j \Pi_{t+1}^{-1})\right], \tag{A.1}$$

$$\text{s.t.} \quad (1-\pi_t^j)E_t^N\left[\Lambda_{t,t+1}\theta V_{t+1}\left(N_{t+1}^j\right) + (1-\theta)\Big(1 - \frac{\overline{b}_t^j}{R_{t+1}^K\Pi_{t+1}}\Big)R_{t+1}^K Q_t K_t^{Bj}\right] \geq \tag{A.2}$$

$$\beta\Lambda_{t,t+1}E_t\left[\Lambda_{t,t+1}\int_{\frac{\overline{b}_t^j}{R_{t+1}^K\Pi_{t+1}}}^{\infty}\theta V_{t+1}\left(N_{t+1}^j\right) + (1-\theta)\Big(\omega - \frac{\overline{b}_t^j}{R_{t+1}^K\Pi_{t+1}}\Big)R_{t+1}^K Q_t K_t^{Bj} d\tilde{F}_{t+1}(\omega)\right],$$

$$(1-\pi_t^j)\beta E_t^N[\Lambda_{t,t+1}Q_t K_t^{Bj}\overline{b}_t^j\Pi_{t+1}^{-1}] + \pi_t^j\beta\mathbb{E}_t^R[R_{t+1}^K Q_t K_t^{Bj}] \geq D_t^j. \tag{A.3}$$

We define $\overline{D}_t^j = \overline{R}_t D_t^j$ and $\overline{b}_t^j = \left(\overline{R}_t D_t^j\right)/(Q_t K_t)$. As shown step-by-step in Rottner (2023), Appendix B, we can use a guess and verify approach to derive the incentive and participation constraint:

$$(1-\pi_t)\mathbb{E}_t^N\left[\Lambda_{t,t+1}R_{t+1}^K(\theta\lambda_{t+1} + (1-\theta))\big(1 - e^{\frac{-\psi}{2}} - \Omega_{t+1}\big)\right] = \pi_t\mathbb{E}_t^R\left[\Lambda_{t,t+1}R_{t+1}^K\big(e^{-\frac{\psi}{2}} - \overline{\omega}_{t+1} + \Omega_{t+1}\big)\right], \tag{A.4}$$

$$(1-\pi_t)\mathbb{E}_t^N\left[\beta\Lambda_{t,t+1}\overline{R}_t^D D_t] + \pi_t\mathbb{E}_t^R[\beta\Lambda_{t,t+1}R_{t+1}^K Q_t K_t^B\right] = D_t\ . \tag{A.5}$$

Note that the incentive constraint and the participation constraint do not depend on intermediary j specific values. The multiplier for the incentive constraint (κ_t) and participation constraint (λ_t) are given as:

$$\kappa_t = \frac{\beta(1-\pi_t)\mathbb{E}_t^N\Lambda_{t,t+1}\left[\lambda_t - (\theta\lambda_{t+1} + 1 - \theta)\right]}{(1-\pi_t)\mathbb{E}_t^N\Lambda_{t,t+1}\left[(\theta\lambda_{t+1} + 1 - \theta)\widetilde{F}_{t+1}(\overline{\omega}_{t+1})\right] + \pi_t\mathbb{E}_t^R\Lambda_{t,t+1}\left[(\theta\lambda_{t+1} + 1 - \theta)\left(1 - \widetilde{F}_{t+1}(\overline{\omega}_{t+1})\right)\right]}, \tag{A.6}$$

$$\lambda_t = \frac{(1-\pi_t)\mathbb{E}_t^N\Lambda_{t,t+1}R_{t+1}^K[\theta\lambda_{t+1} + (1-\theta)](1-\overline{\omega}_{t+1})}{1 - (1-\pi_t)\mathbb{E}_t^N[\Lambda_{t,t+1}R_{t+1}^K\overline{\omega}_{t+1}] - \pi_t\mathbb{E}_t^R[\Lambda_{t,t+1}R_{t+1}^K]}. \tag{A.7}$$

B Global Solution Method

We solve the model with global methods to account for the runs on the financial sector and the stochastic transition path to a net zero economy. We extend the global solution

[17] We also refer to Adrian and Shin (2014) and Nuño and Thomas (2017).

method of Rottner (2023), which can solve the type of run models studied here, to feature stochastic transition paths. Incorporating this feature is key to evaluating the financial stability impact of climate policies during the transition and in the long-run.

The state variables are previous period capital, current period net worth, the risk shock and the sunspot shock, that is $X_t = \left\{K_{t-1}, N_t, \epsilon_t^{\xi}, \epsilon_t^{\pi}\right\}$. We also condition the solution on the carbon tax path $\{\tau_l^c\}_{l=t}^{\infty}$ to allow for changing carbon taxes. In particular, we consider two distinct cases for the tax path in the model.

1. Long-run equilibrium: The tax path is constant. This case is relevant once the transition is completed or before agents anticipate future carbon taxation. The tax sequence is then constant for all periods, that is $\tau_t^c = \tau^c, \forall t$.

2. Transition dynamics: The tax path follows a commonly known path with time-varying taxes. Specifically, the tax path consists of two parts: First, the tax rate changes over time until its terminal level is reached in period T_{max}, that is $\{\tau_l^c\}_{l=t}^{T_{max}}$. This part reflects the transition. Once the maximum tax rate is reached, the tax remains constant, that is $\tau_t^c = \tau^c, \forall t > T_{max}$. At this level, we are back in the first case denoted as long-run equilibrium.

While the tax path is constant and known by the agents, the economy is subject to shocks. Therefore, we are analyzing stochastic transition dynamics, in which the agents expect the materialization of shocks.[18] The remaining parameters of the model are summarized as θ^P.

To find the model solution, we solve the policy functions for the asset price, consumption, the multiplier on the participation constraint, a measure of the promised repayments, and inflation. The policy function in period t depends on the state variables, the parameters, and the sequence of carbon shocks from period t onwards:

$$Q_t(X_t; \{\tau_l^c\}_{l=t}^{\infty}, \Theta^P), C_t(X_t; \{\tau_l^c\}_{l=t}^{\infty}, \Theta^P), \bar{b}_t(X_t; \{\tau_l^c\}_{l=t}^{\infty}, \Theta^P),$$
$$\Pi_t(X_t; \{\tau_l^c\}_{l=t}^{\infty}, \Theta^P), \quad \text{and} \quad \lambda_t(X_t; \{\tau_l^c\}_{l=t}^{\infty}, \Theta^P).$$

We also solve for the law of motion of net worth and the probability of observing a run next period:

$$N_t'(X_t, \epsilon_{t+1}^{\xi}; \{\tau_l^c\}_{l=t}^{\infty}, \Theta^P), \quad \text{and} \quad \pi_t(X_t; \{\tau_l^c\}_{l=t}^{\infty}, \Theta^P),$$

where ϵ_{t+1}^{ξ} are the risk shock realizations next period. Once we have solved for these objects, we can back out all other variables.

The solution algorithm uses time iteration with linear interpolation (see, e.g., Richter et al., 2014). We also use an additional piecewise approximation of the policy functions

[18] The framework can be easily extended by tax paths that are subject to shocks themselves. In such a case, the shock component of the tax rate enters as a state variable.

by deriving separate policy functions to approximate the run and normal equilibrium. The expectations are approximated with Gauss-Hermite quadrature.

Our global solution algorithm is summarized below:

1. We first define a grid for the state variables (without the sunspot shock): $\boldsymbol{X} \in [\underline{K}_{t-1}, \overline{K}_{t-1}] \times [\underline{N}_t, \overline{N}_t] \times [\underline{\sigma}_t, \overline{\sigma}_t] \times [\underline{A}_t, \overline{A}_t]$. Using Gauss-Hermite quadrature, we set up integration nodes for the expectations with respect to the risk shock $\boldsymbol{\epsilon} \in [\underline{\epsilon^{\xi}}_{t+1}, \overline{\epsilon^{\xi}}_{t+1}]$. We denote the considered tax path by $\{\tau_l^c\}_{l=t}^{\infty}$.

2. We guess the piecewise linear policy functions to initialize the algorithm. This includes a separate guess for the policy function for each different carbon tax level. As an example, we have the following set of policy functions for the asset price:

$$\{Q_t(X_k; \{\tau_l^c\}_{l=t}^{\infty}, \Theta^P)\}_{t=t_0}^{\infty}$$

   While this would result in an infinite set of policy functions, we can exploit that policy functions are time-invariant once the terminal tax rate is reached. Therefore, we can simplify the set of policy functions that we need to solve for the two different cases that we consider:

   (a) Long-run equilibrium: The tax path is time-invariant. As a consequence, the policy function is not path-dependent. We then have:

$$Q_t(X_t; \{\tau_l^c\}_{l=t}^{\infty}, \Theta^P) = Q(X_t; \{\tau_l^c\}_{l=t}^{\infty}, \Theta^P) = Q(X_t; \tau^c, \Theta^P), \forall t$$

   (b) Transition dynamics: At the beginning, the tax path changes over time, while it then converges to the terminal rate. Therefore, we have two different problems at different stages in time:

$$\forall t \leq T_{max} : \{Q_t(X_t; \{\tau_l^c\}_{l=k}^{\infty}, \Theta^P)\}_{t=t_0}^{T_{max}} = \{Q_t(X_t; \{\tau_l^c\}_{l=k}^{T_{max}}, \Theta^P)\}_{t=t_0}^{T_{max}},$$
$$\forall t > T_{max} : Q_t(X_t; \{\tau_l^c\}_{l=t}^{\infty}, \Theta^P) = Q(X_t; \{\tau_l^c\}_{l=t}^{\infty}, \Theta^P) = Q(X_t; \tau_{T_{max}}^c, \Theta^P).$$

   This notation highlights that we can use a time iteration algorithm to solve for the policy functions. If we are in an infinite time horizon, that is either the long-run equilibrium or at the terminal tax rate, we solve the problem using policy function iteration. We can divide the transition dynamics in a finite horizon problem during the transition and an infinite horizon problem with the terminal tax rate after $t > T_{max}$. We first solve the infinite horizon problem using policy function iteration as before. We can then use this to conduct backward induction to solve the finite horizon problem of the transition.

   While we discussed this for the specific asset price policy function, this generalizes to all policy functions that we need to solve. In particular, we need a guess for all policy functions, the probability that a run occurs next period, and the law of motion of net worth. The latter $N_t'(X_t, \epsilon_{t+1}^{\xi}; \Theta^P)$ provides a mapping from state variables today into net worth next period at each integration point coming from Gauss-Hermite quadrature.

3. We solve for all time t variables for a given state vector and tax path ahead, focusing on the no run equilibrium. We use the law of motion for net worth and the run probability from the previous iteration j as given. We also need to calculate our next-period values using policy functions. In the infinite horizon problem, we use the guess of the policy function iteration from iteration $j-1$. In the finite horizon problem, we use the policy function from period $t+1$, i.e. $Q_{t+1}(\cdot)$. Expected values are computed using Gauss-Hermite quadrature. We then use a numerical root finder to minimize the error of these equations. The inputs are the time-invariant policy functions in the infinite horizon problem and the period t policy functions for the finite horizon problem:

$$\begin{aligned}
\text{err}_1 &= \left(\frac{\Pi_t}{\Pi} - 1\right)\frac{\Pi_t}{\Pi} - \left(\frac{\epsilon}{\rho^r}\left(MC_t - \frac{\epsilon - 1}{\epsilon}\right) + \Lambda_{t,t+1}\left(\frac{\Pi_{t+1}}{\Pi} - 1\right)\frac{\Pi_{t+1}}{\Pi}\frac{Y_{t+1}}{Y_t}\right), \\
\text{err}_2 &= 1 - \beta \mathbb{E}_t \Lambda_{t,t+1}\frac{R_t^I}{\Pi_{t+1}}, \\
\text{err}_3 &= (1-\pi_t)\mathbb{E}_t^N\left[\beta\Lambda_{t,t+1}\overline{R}_t D_t\right] + \pi_t \mathbb{E}_t^R\left[\beta\Lambda_{t,t+1}R_{t+1}^K Q_t K_t^B\right] - D_t, \\
\text{err}_4 &= (1-\pi_t)\mathbb{E}_t^N\left[\Lambda_{t,t+1}R_{t+1}^K(\theta\lambda_{t+1} + (1-\theta))(1 - e^{\frac{-\psi}{2}} - \Omega_{t+1})\right] \\
&\qquad - \pi_t \mathbb{E}_t^R\left[\Lambda_{t,t+1}R_{t+1}^K(e^{-\frac{\psi}{2}} - \overline{\omega}_{t+1} + \Omega_{t+1})\right], \\
\text{err}_5 &= \lambda_t - \frac{(1-\pi_t)\mathbb{E}_t^N \Lambda_{t,t+1}R_{t+1}^K[\theta\lambda_{t+1} + (1-\theta)](1-\overline{\omega}_{t+1})}{1 - (1-\pi_t)\mathbb{E}_t^N[\Lambda_{t,t+1}R_{t+1}^K\overline{\omega}_{t+1}] - \pi_t\mathbb{E}_t^R[\Lambda_{t,t+1}R_{t+1}^K]}.
\end{aligned}$$

4. We now take our policy functions as well as the law of motion for net worth and the run probability from iteration $j-1$ as given. Using these objects, we calculate the variables for the period t and $(t+1)$ variables. We use these points to calculate N_{t+1} across the integration nodes and update the law of motion for net worth:

$$N_{t+1} = \max\left[R_{t+1}^K Q_t K_t^B - \overline{R}_t D_t, 0\right] + (1-\theta)\zeta K_t. \tag{B.1}$$

To determine whether the run equilibrium is supported on a specific node, we compute

$$R_{t+1}^K Q_t K_t^B - \overline{R}_t D_t \leq 0. \tag{B.2}$$

Table B.1: Targeted Moments

Moment	Data	Model
Mean leverage (p.p.)	15.5	15.5
Standard deviation leverage (p.p.)	3.0	3.0
Autocorrelation leverage	0.96	0.95
External finance premium	3.0	3.0
Share of assets held by intermediaries	33%	35%
Crisis probability	2% p.a.	2.1% p.a.

which evaluates to one if a run is possible.[19] This can be now used to evaluate the probability of a run next period based on Gauss-Hermite quadrature.

5. We repeat the steps 3 and 4 focusing also on the run equilibrium in the current period.

6. We update the policy functions, the law of motion for net worth, and the run probability using a weighted combination of our results from iteration j and the previous guess.

7. We repeat the steps 3 - 6 until the errors of all functions (policy functions, law of motion of net worth, and the probability of a run) are sufficiently small at each point of the discretized state space.

8. The infinite horizon problem is solved at this stage.

   For the finite horizon problem, we redo the steps 3 - 7 for all periods backwards, i.e. in the order of $T_{max}-1, T_{max}-2, ..., t_0+1$, and finally t_0. Furthermore, we also need to calculate one additional object. The law of motion that gives the mapping from the period t_0-1 without the tax path and the period in which the transition arrives unanticipated: $N'_{t_0-1}(X_{t_0-1}, \epsilon^{\xi}_{t_0}; \{\tau^c_l\}^{\infty}_{l=t_0-1}, \Theta^P)$. For this, we use step 4 using the old policy functions for the period $t_0 - 1$ (e.g. the previous long-run equilibrium) and the newly obtained policy functions for period $t_0 - 1$.

We can now use the obtained functions to simulate the model's ergodic distribution and transition dynamics. In Table B.1, we demonstrate that our baseline calibration without carbon taxes is able to fit key moments in the data well.

[19] The equation implies a zero and one indicator, which is a very unsmooth object. As a consequence, we use the following functional forms based on the exponential function to determine the run probability in this state of the world: $\frac{\exp(\zeta_1(1-D_{t+1}))}{1+\exp(\zeta_1(1-D_{t+1}))}$ where $D_{t+1} = \frac{R^k_{t+1}}{R^D_t}\frac{\phi}{\phi-1}$ at each calculated N_{t+1}. We set ζ_1 to 500 which ensures sufficient steepness. While this approximation induces smoothness, it is still very close to an indicator function with 0 and 1 values.

C Illustrating the Non-Linear Effect of Carbon Taxes

To illustrate the workings of our non-linear model, Figure C.1 displays the impulse response functions of key variables to a positive two standard deviation shock to exogenous risk ξ_t at different stages of the net zero transition. The solid black line refers to the case without carbon tax, the dashed red line is eight quarters into the transition, and the dotted green line refers to the terminal equilibrium with net zero emissions.

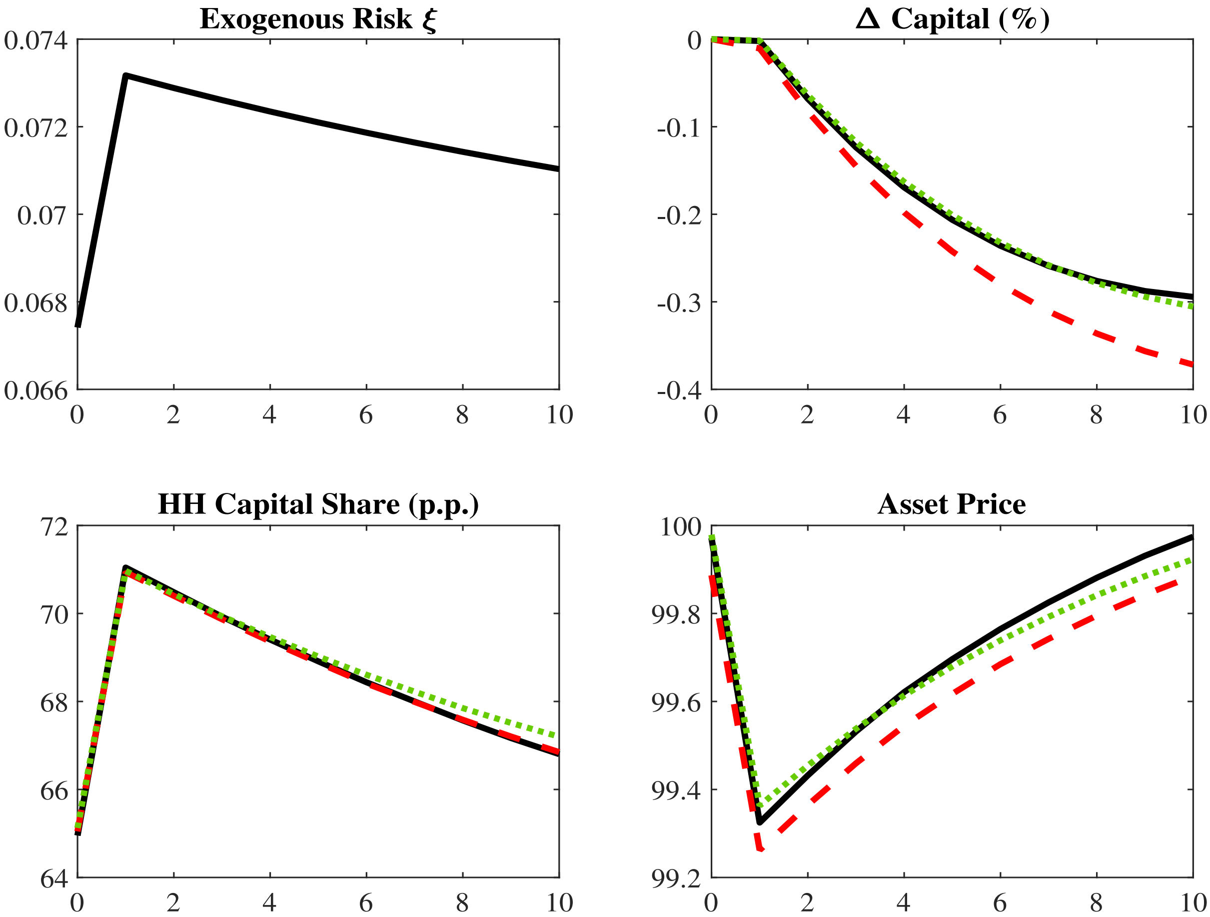


Figure C.1: Impulse response function to a positive two standard deviation risk shock at different stages of the transition. The solid black line refers to the case without carbon tax, the dashed red line is eight quarters into the transition, and the dotted green line refers to the terminal equilibrium with net zero emissions. The IRFs are obtained by simulating the model 10.000 times after a burn-in of 1000 quarters. The change in capital is expressed relative to the period before the shock. The household capital share is in percentage points. The asset price is normalized to 100 in the long run mean.

By increasing risk-shifting incentives, this shock tightens intermediaries' leverage constraint, which is associated with a contraction in credit supply, economic activity, and investment. The upper right panel shows this specifically for total capital, which persistently declines by up to 0.4 percent. Deleveraging is achieved by selling some capital to households, who hold more than 70% of the capital stock, compared to 65% in the long run mean. Importantly, the increase in household capital holdings is almost identical, irrespective of the stage of the transition. By contrast, the asset price response is quite different. The drop is much more pronounced shortly after the shift onto the *Paris-aligned* path, as capital holdings are too large in light of the now smaller productivity of capital. As a consequence, households are only willing to hold capital at a lower price, reflected by the dotted red line in the bottom left panel of Figure C.1. This reinforces the pressure on intermediaries to sell, which further depresses investment and also increases the run probability.

Notably, the long run equilibrium with net zero emissions experiences a slightly smaller asset price drop to the same shock, which is in line with the smaller crisis probability in the long run. These dynamics illustrate how a sudden shift from one monotonically increasing tax path to a steeper, but still monotonic, tax path can have non-monotonic effects on the crisis probability.

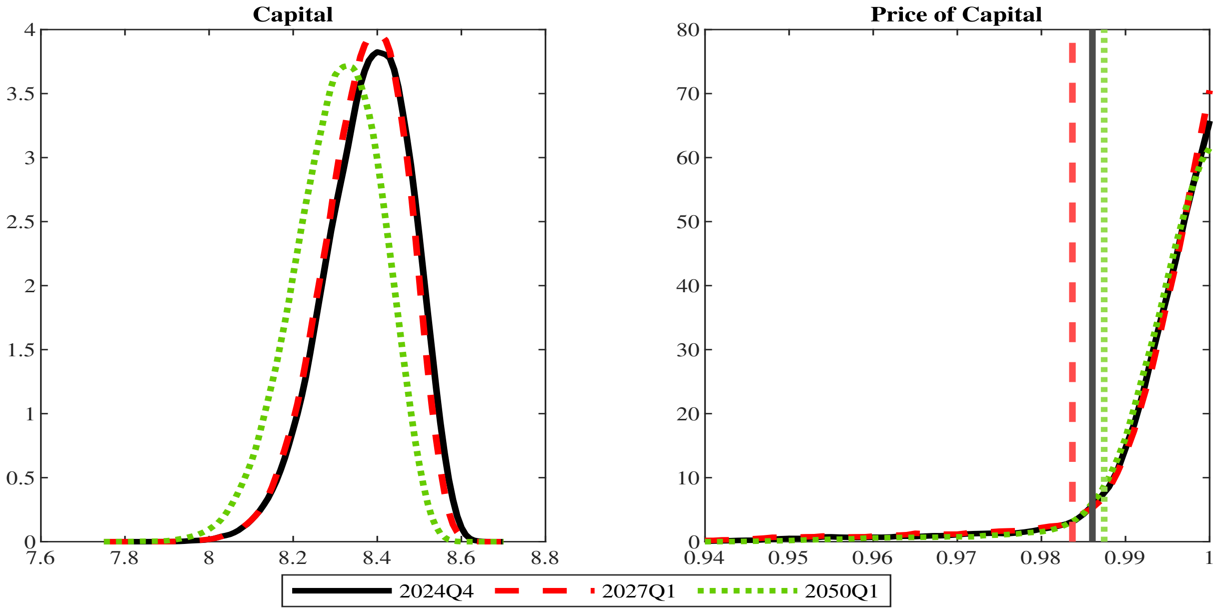


Figure C.2: Non-Linearities during the transition to net zero. The distribution of endogenous model objects at different stages of the Paris-aligned transition is shown. The distributions obtained by simulating the model 100,000 times with a burn-in period of 200 quarters. Capital holdings are expressed relative to quarterly GDP. The 5%-quantiles are indicated by vertical lines for the asset price.

In Figure C.2, we show the distribution of total capital and the price of capital, at different points of the transition path. The last quarter on the *current trajectory* is indicated by solid black lines. Dotted red lines represent the distribution 10 quarters into the transition, while the dotted green lines correspond to the first quarter at which taxes reach net zero. The left panel shows total capital, which declines from its initial distribution in a quite monotonic fashion towards the long-run equilibrium. In sharp contrast, the non-linear implications of the transition are represented by the price of capital in the right panel. Focusing on the the 5% quantiles, indicated by vertical lines, we observe a more pronounced tail ten quarters into the transition (dashed red line), while the tail features less mass in the new long-run equilibrium (dotted green line).

D Model Modifications

In this section, we provide more details on some model extensions and climate policy changes.

D.1 Climate Policy and Aggregate Capital

The transmission from climate policy to financial stability depends on capital accumulation in the real sector. In our baseline one-sector model with technology choice, carbon taxes induce the capital stock to fall in the long-run, which improves financial stability in the long run, at the cost of elevated crisis probabilities along the transition. In this section, we demonstrate that a similar effect of carbon taxes on aggregate capital can be obtained in different models of the production sector. We focus on the long-run implications and abstract from financial frictions, nominal rigidities, and strong general equilibrium effects through aggregate demand, i.e., we substantially increase the curvature of labor supply disutility.

First, we show that carbon taxes have the same effect on aggregate capital holdings in a model with a clean and a dirty sector. This two-sector model largely follows Giovanardi et al. (2023). There is no technology choice, but one sector generates emissions during the production process (dirty), while the other sector operates an emission-free technology (clean). The sector-specific production functions are given by $Y_{t,b} = K_{t,b}^{\alpha} N_{t,b}^{1-\alpha}$ and $Y_{t,g} = K_{t,g}^{\alpha} N_{t,g}^{1-\alpha}$, while emissions satisfy $e_t = Y_{t,b}$. Those two goods are combined into a final consumption good using a Cobb-Douglas production function, i.e. $Y_t = AY_{t,b}^{\nu} Y_{t,g}^{1-\nu}$. As the red dotted line in Figure G.1 demonstrates, the implications for aggregate capital are very similar to the one-sector model with the option of adopting clean technologies. The reason is that clean and dirty intermediate goods are imperfect substitutes in the final production function, such that taxes on the dirty sector can not be fully compensated by more investment and production in the dirty sector.

Second, we consider a model with an energy sector. [20] Here, final good producers use energy as an input using a Cobb-Douglas technology $Y_t = AK_{t-1}^{\theta} M_t^{\nu} N_t^{1-\theta-\nu}$. Emissions are proportional to energy usage M_t and taxed in the same fashion as in the baseline model. The dotted cyan line indicates that the effect on capital accumulation is somewhat muted, since the production sector re-allocates away from energy towards capital and labor. Nevertheless, the negative productivity wedge dominates, such that K_t decreases in the long-run carbon tax.

Lastly, we assume that emissions are only associated with using capital in the production function, i.e. $e_t = K_t$, while the aggregate production function is the same as in the baseline model. We again maintain the same functional form for the cost of using clean

[20] Golosov et al. (2014) explicitly model energy usage in the aggregate production function. In their framework, ambitious climate policy leads to an increase in the cost of energy in the medium-run

technologies, such that the wedge ξ_t inherits the functional form of the baseline model, but merely affects the marginal product of capital. Formally, the marginal product of capital is now given by $Z_t = p_t \alpha \frac{Y_t}{K_{t-1}} - \xi_t$, while the wedge drops out of the labor demand condition $W_t = (1-\alpha)\frac{Y_t}{L_t}$. In this model, the effect of carbon taxes on aggregate capital is amplified, as producers re-allocate from capital towards labor, as the dotted blue line in Figure G.1 reveals.

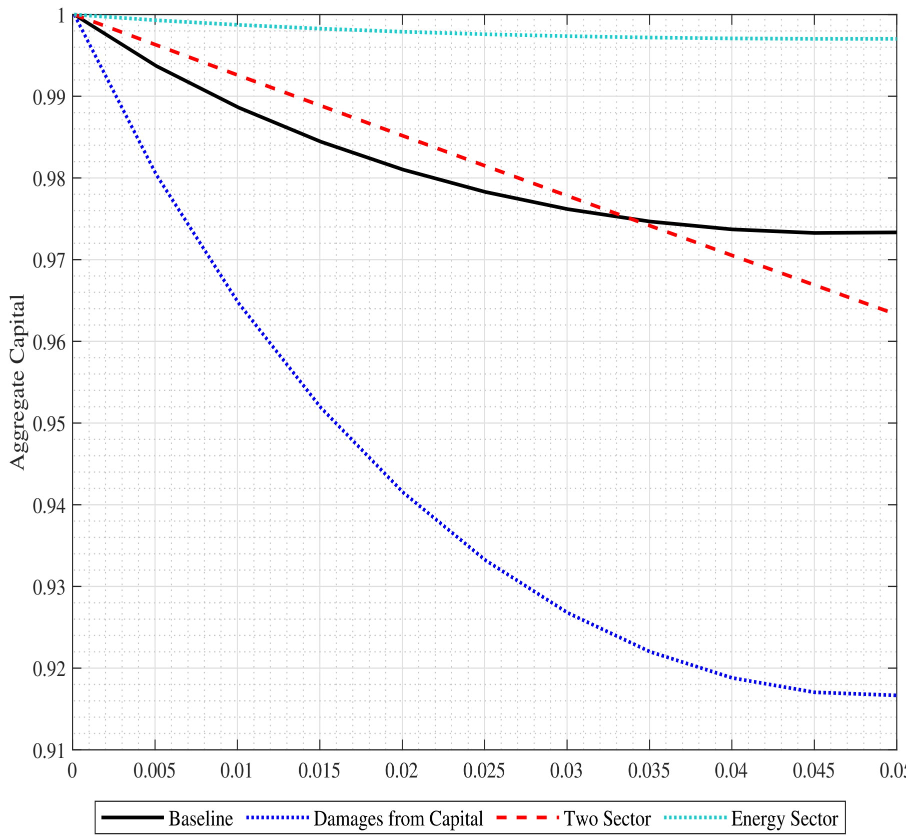


Figure G.1: This graph shows the effect of carbon taxes (x-axis) in model units on aggregate capital (y-axis) in different models. A tax of $\tau_t^c = 0.05$ implements net zero in the baseline model. For each model, aggregate capital is normalized to one in the case without carbon taxes.

D.2 Fiscal Subsidies

We are changing the underlying assumption regarding the use of carbon tax revenues. So far, we assumed that carbon tax revenues are rebated to households in a lump sum fashion. Now, the carbon tax revenue is used as an subsidy for firms' adoption of clean technologies. The subsidy is financed with the carbon tax revenue so that the per-unit subsidy is given by $((1-\eta_t^*)\tau_t^c)/\eta_t^*$. The share of clean technology firms η_t^* enters the technology choice problem of each individual firm, as they take the size of the subsidy as exogenously given. The subsidy effectively reduces the cost of operating the clean technology to $b_1 \eta_t^{b_2} - ((1-\eta_t^*)\tau_t^c)/\eta_t^*$ and the indifference point in equilibrium is given by

$$\eta_t^* = \min\left\{\left(\frac{\tau_t^c}{b_1}\right)^{\frac{1}{b_2+1}}, 1\right\}, \tag{E.1}$$

where we have used the additional equilibrium condition $\eta = \eta^*$. Note that the share of clean firms with fiscal subsidies is larger than in the baseline model, which is given by equation (1), for any given carbon tax. The associated wedge in the return on capital simplifies to $\xi_{t+1} = \frac{\tau_{t+1}^c}{b_2+1}$. As long as the tax is positive, the wedge is always smaller than under the assumption of tax rebates to households. Consistent with the baseline model, we compute the transition dynamics with fiscal subsidies for the *Paris-aligned* tax path consistent with net zero in 2050.

%beginequation

D.3 Shape of the Transition: Back- and Front-Loaded Path

In this section, we describe how we construct non-linear transition transition paths that can be interpreted as advanced and delayed climate policy action, respectively. In both cases, we keep the terminal period at $T_{max} = 2050$ fixed. Delaying ambitious policy action could give the real economy and the financial sector time to prepare for the shift towards emission-free technologies and thereby mitigate the threat of Climate Minsky Moments. The *back-loaded* path is constructed as a linear combination between the *current trajectory* $\tau_t^{current}$ and the tax in the *Paris-aligned* path τ_t^{paris}:

$$\tau_t^{back} \equiv (1 - w_t)\tau_t^{current} + w_t\tau_t^{paris},$$

where the weight is given by $w_t \equiv \frac{t}{T_{max}-T_0}$ for any $t \in [T_0, T_{max}]$. The back-loaded path features a rapid increase in the carbon tax in the last periods before reaching net zero.[21] We also define a front-loaded transition path that adds the (time-varying) difference between the current trajectory and back-loaded taxes $(\tau_t^{amb} - \tau_t^{back})$ to the current trajectory, resulting in a front-loading:

$$\tau_t^{front} \equiv \tau_t^{paris} + \left(\tau_t^{paris} - \tau_t^{back}\right).$$

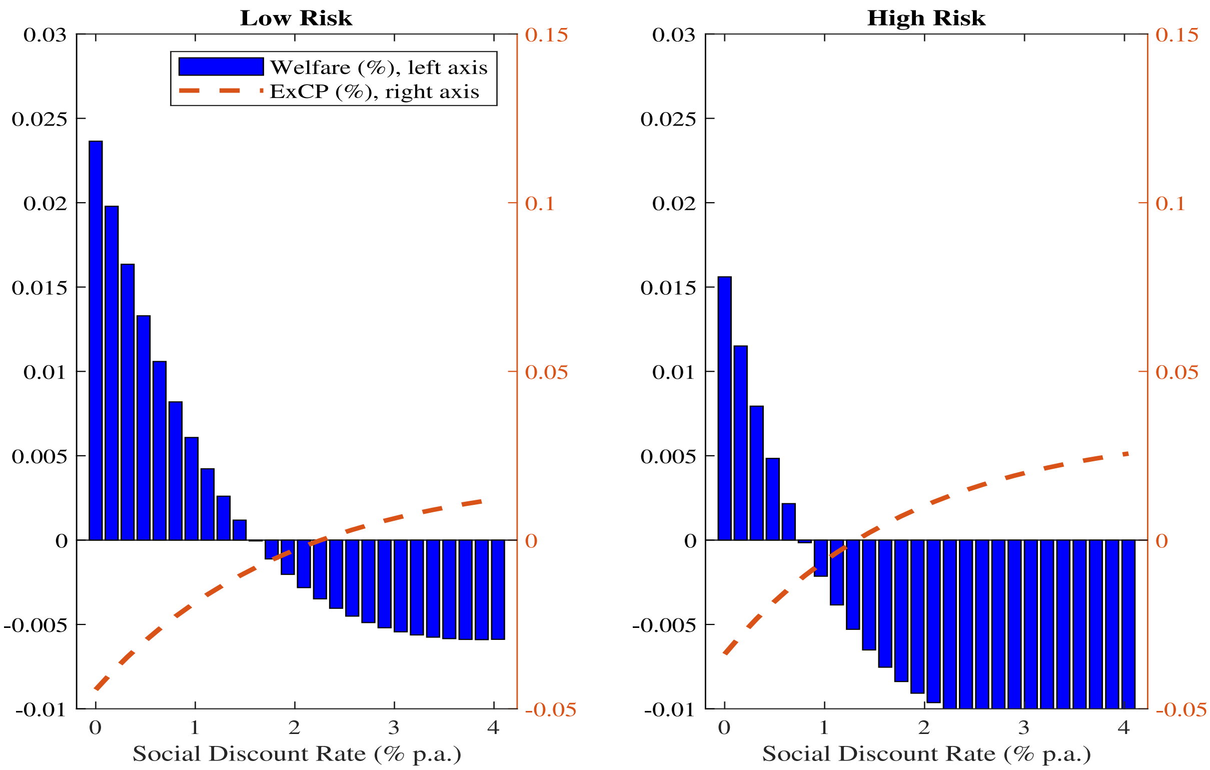
[21] Note that the steep portion of the back-loaded tax path is anticipated as soon as the economy shifts to the new tax path and that the policymaker is fully committed to this path.

E Macropudential and Monetary Policy: Welfare

The state of the economy at the onset of the transition plays an important role for the impact of climate policies on financial stability and welfare. While figure 4 displays the effect on the crisis probability, we show in this section how the financial sectors' loss-absorbing capacity affects the excess crisis probability and the welfare losses from Climate Minsky Moments.

To obtain an appropriate comparison, we impose the same risk shock realizations on the *current trajectory* and display the results in Figure F.1. Comparing the left panel (low risk) to the right panel (high risk), it stands out that the excess crisis probability is consistently larger if the economy's loss-absorbing capacity is small. Consequently, the welfare effect is also smaller for every social discount rate and turns negative at about 1%, while it is only negative for rates exceeding 2% if the loss-absorbing capacity is large. This observation is an outcome of our non-linear model, which shows that the financial stability effects of ambitious climate policy are state-dependent in a non-linear fashion.

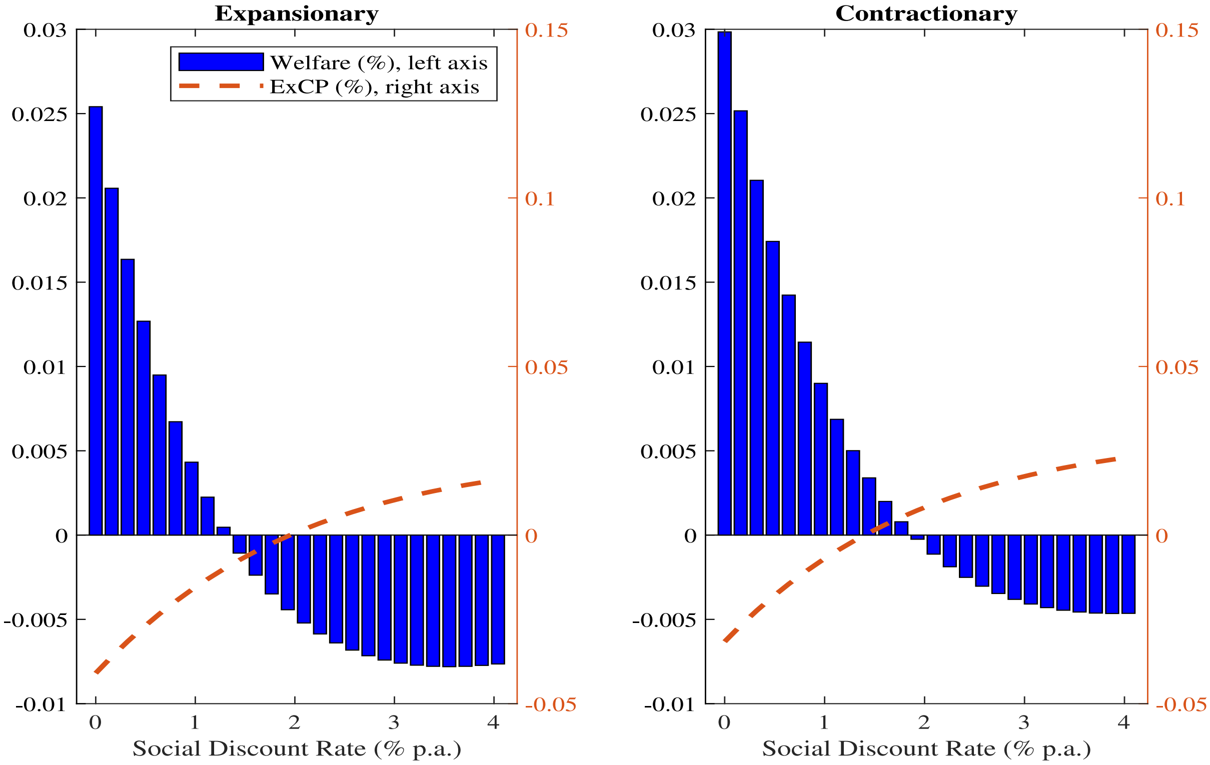
Figure F.1: Financial Cycle: Welfare Effects



Notes: The results are obtained from simulating the model 100,000 times with a burn-in period of 200 quarters.

Similar to the financial sector's loss-absorbing capacity, the stance of monetary policy also affects the likelihood of Climate Minsky Moments. While we have compared crisis probabilities for different monetary policy stances under the same Paris-aligned carbon tax path in figure 5, we show how the monetary policy stance affects the excess crisis probability and the welfare effect of Climate Minsky Moments in Figure F.1.

Figure F.2: Monetary Policy: Welfare Effects



Notes: The results are obtained from simulating the model 100,000 times with a burn-in period of 200 quarters.