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Modelling monetary and fiscal policy to achieve climate goals

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ABSTRACT

This study develops a two-sector dynamic stochastic general equilibrium model with financial accelerator frictions, following Bernanke et al. (1999), to examine how monetary, financial, and fiscal instruments can steer bank lending toward climate-related objectives. The model distinguishes between green and brown production sectors and evaluates three finance-based policy tools: broad reserve requirements, targeted central bank refinancing for green lending, and government guarantees for loans to low-carbon firms. To benchmark these instruments against a standard environmental policy, the model also introduces a Pigouvian carbon tax that prices sectoral emissions according to their emission intensities. The results show that reserve requirement policy mainly operates through aggregate liquidity and generates relatively high transitional volatility, with limited long-run reallocation toward green activity. Targeted green refinancing is the most stable and effective finance-based instrument: it compresses the external finance premium for green firms, reallocates credit toward cleaner production, and delivers more persistent emission reductions. Government loan guarantees also support green lending and technological accumulation, but their transition dynamics are more oscillatory and may generate short-run scale effects. The Pigouvian carbon-tax benchmark clarifies that direct carbon pricing and green financial policies operate through different margins: the former raises the production cost of emissions-intensive activity, while the latter lowers the financing cost of green investment. These findings highlight the importance of targeted financial interventions and carbon-pricing benchmarks in designing policy frameworks for the low-carbon transition and financial stability.

1. Introduction

Climate change poses profound risks for both the real economy and the financial system. Despite the growing momentum for decarbonization since the 2015 Paris Agreement, progress toward net-zero commitments remains insufficient (International Energy Agency, 2022; Jeudy-Hugo et al., 2021). This raises the question of how monetary and fiscal policies can complement environmental regulation and carbon pricing in directing financial flows toward sustainable investment. Understanding these dynamics requires a framework that can capture the interaction between credit markets, firm heterogeneity, and the relative cost of "brown" versus "green" investment.

Climate-oriented credit policy raises an institutional concern because it represents a marked deviation from standard central bank

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practice, in which policy is typically directed toward aggregate objectives such as price stability, macroeconomic stabilization, and financial stability rather than support for specific sectors. This paper does not advocate sectoral credit allocation as a general policy rule, nor does it seek to describe current central bank practice. Rather, it provides a positive theoretical analysis of how targeted financial instruments transmit through bank balance sheets, firm leverage, external finance premia, and emissions when green and brown credit exposures are observable. This allows us to compare these finance-based mechanisms with fiscal guarantees and a Pigouvian tax benchmark.

Climate-related central bank policies and proposals have broadly followed two approaches. The first focuses on how climate change affects financial stability and central bank objectives. Climate change may increase financial-system vulnerabilities through losses to leveraged intermediaries, disruptions in market functioning, or sudden repricing of carbon-intensive assets. A growing literature therefore examines transition risks associated with the revaluation of carbon-intensive assets following policy changes, technological shifts, and changes in market preferences (Andersson et al., 2018; Battiston et al., 2017; Caldecott et al., 2021; Stolbova et al., 2018), as well as how central banks can integrate climate risks into their operations and policy frameworks (Bolton et al., 2020; Campiglio et al., 2023; Svartzman et al., 2021). The second, more controversial approach asks whether monetary and financial-policy instruments could more directly support decarbonization. Some proposals aim to lower the relative cost of capital for low-carbon sectors through preferential refinancing terms or differentiated reserve and capital requirements (Krogstrup & Oman, 2019; Monnet & van 't Klooster, 2023). Others advocate more direct interventions, such as central banks issuing credit to non-financial firms, partnering with dedicated intermediaries, or conditioning access to refinancing on banks' green lending performance (Anderson, 2015; Ryan-Collins et al., 2013; Van Lerven & Ryan-Collins, 2018). Additional proposals include green quantitative easing, exclusion of carbon-intensive assets from central bank portfolios, revised collateral eligibility rules, government guarantees for green projects, and forward guidance (Campiglio, 2016; Oustry et al., 2021; Prasad et al., 2022). Despite this growing policy debate, quantitative DSGE models that jointly analyze these instruments in the presence of financial frictions remain limited.

We contribute to this literature by developing a dynamic stochastic general equilibrium (DSGE) model with financial frictions that builds on the Bernanke et al. (1999) financial accelerator framework. The BGG model is a natural starting point because it shows how firm balance sheets and credit spreads amplify macroeconomic shocks. To adapt the framework to the climate context, we extend it in three ways. First, we distinguish between green and brown firms whose relative competitiveness depends on the elasticity of substitution between green and brown goods, capturing technological barriers to the low-carbon transition (Acemoglu et al., 2012). Second, we allow the central bank to operate targeted refinancing facilities and differentiated reserve requirements that affect banks' incentives and funding conditions for supplying green credit. Third, we incorporate government loan guarantees that reduce lenders' expected losses on eligible green loans, thereby lowering borrowing costs and encouraging green investment. These modifications enable us to examine how monetary and fiscal instruments affect credit allocation, firm leverage, and macroeconomic outcomes, as well as their implications for carbon emissions.

Since a standard response to emissions externalities is a Pigouvian carbon tax, the model also introduces a sectoral Pigouvian carbon-tax benchmark. The tax applies to emissions from both green and brown sectors, but the effective unit tax burden is larger for brown production because brown firms have higher emissions intensity. This benchmark clarifies how direct carbon pricing differs from finance-based instruments: Pigouvian taxation raises production costs according to emissions intensity, whereas green refinancing and loan guarantees operate indirectly by reducing green firms' funding costs and default-risk premia. In the Pigouvian carbon-tax benchmark introduced below, this assumption is relaxed by allowing emissions from both sectors to enter firms' effective production costs through a carbon tax, with a larger unit cost imposed on brown production because of its higher emissions intensity.

The BGG structure is particularly useful for this purpose because it separates two mechanisms that are central to our analysis. The first is the production and emissions channel, through which sectoral technology and output determine carbon emissions. The second is the financial-contracting channel, through which firm net worth, leverage, and default risk determine the external finance premium. In addition, evidence suggests that the BGG model replicates the relationship between firm net worth, the external finance premium, and investment more effectively than alternatives such as Gertler and Karadi (2011), which emphasize intermediary-side leverage (Rannenberg, 2016). In our framework, climate risk is not assumed to be identical to BGG bankruptcy risk. Rather, climate-related heterogeneity affects sectoral production, emissions, and policy treatment, while BGG-style financial frictions determine how changes in credit conditions are amplified through firm balance sheets. This distinction allows us to study how climate-oriented policy wedges are transmitted through credit spreads, leverage, and investment.

The simulations generate three main findings. First, low substitutability between green and brown goods slows the reallocation of production toward the green sector, implying a more gradual and costly transition. Second, changes in reserve requirements operate primarily through aggregate liquidity and therefore do not generate a persistent sectoral wedge between green and brown firms; that is, they do not create a lasting difference in relative financing conditions or incentives across the two sectors. Third, targeted refinancing is more effective than broad reserve requirements in reducing emissions because it lowers green banks' funding costs and compresses the external finance premium of green firms. Government loan guarantees also support green lending by reducing expected default losses, but their effects are more sensitive to the design and persistence of the guarantee. Compared with a Pigouvian carbon tax, these finance-based instruments operate indirectly through bank balance sheets, credit spreads, firm leverage, and external finance premia. By contrast, the Pigouvian carbon tax works directly through a sectoral production-cost wedge: it raises firms' effective production costs according to emissions intensity, with a larger burden on brown firms because of their higher emissions intensity.

The rest of the paper is organized as follows. Section 2 presents the model. Section 3 describes the calibration. Section 4 reports the impulse-response analysis and compares the policy instruments with the Pigouvian tax benchmark. Section 5 concludes.

2. The model

2.1. Overview

The economy consists of a representative household, green and brown production sectors, capital producers, banks, a central bank, and a fiscal authority. The representative household supplies homogeneous labour, consumes the final good, holds bank deposits, and owns productive firms, banks, and capital producers. Profits from these entities are rebated to the household as dividends. This ownership structure closes the model and explains the profit-income term in the household budget constraint.

On the production side, there are many monopolistically competitive green firms that collectively produce a composite green good, $Y_{g,t}$. Similarly, there are many monopolistically competitive brown firms that collectively produce a composite brown good, $Y_{b,t}$. Green and brown firms hire labour from households and rent capital from capital producers. These sectoral goods are then combined by a competitive final-good producer through a CES technology to produce the aggregate final good, Y_t, which can be used for consumption and investment. Capital producers transform final goods into new capital and rent installed capital to green and brown firms at competitive rental rates.

Nominal rigidity is introduced at the level of differentiated green and brown producers through Calvo price setting. The sectoral aggregators and the final-good producer are competitive. Wages and rental rates of capital adjust competitively, while loan rates are determined by bank optimality conditions and by the external finance premium generated in the BGG financial-contracting problem.

Firms finance capital partly with internal net worth and partly with bank loans. Following Bernanke et al. (1999), idiosyncratic firm-level return shocks generate default risk and monitoring costs, giving rise to an external finance premium that increases with leverage. Banks intermediate funds between households and firms by collecting deposits and extending loans. For tractability, banks are differentiated by loan portfolio rather than by institutional type: green banks lend to green firms, and brown banks lend to brown firms. This classification should be interpreted as a modelling device that captures green and brown credit exposures, rather than as a claim that real-world sectoral classification is costless.

The central bank and fiscal authority introduce three policy instruments. First, the central bank adjusts reserve requirements, which affect aggregate bank liquidity. Second, it provides targeted refinancing to banks that lend to green firms, lowering the funding cost of green credit. Third, the fiscal authority provides loan guarantees for eligible green loans, reducing the expected default-loss component of green lending. These instruments affect credit allocation, firm leverage, and the relative user cost of capital across green and brown sectors.

The model contains three types of uncertainty. First, sectoral technology processes, $A_{g,t}$ and $A_{b,t}$, affect the production efficiency and emission intensity of green and brown firms, respectively. Second, idiosyncratic firm-level return shocks, $\omega_{g,t}$ and $\omega_{b,t}$, enter the BGG loan-contracting problem and determine default outcomes, monitoring costs, and the external finance premium. These shocks are distinct from sectoral technology shocks: they capture ex post return risk rather than aggregate productivity risk. Because there is a continuum of firms, idiosyncratic shocks average out in aggregate quantities, but their distribution affects equilibrium loan rates through default probabilities. Third, the model includes policy shocks to the reserve requirement ratio, the green refinancing rate, and the government guarantee parameter. These policy shocks operate through bank liquidity, green-bank funding costs, and green-firm default risk, respectively.

Carbon emissions are computed from sectoral output and technology. In the baseline model, emissions are treated as an unpriced negative externality: they do not directly enter household utility or firm production costs. They are instead used to evaluate the environmental consequences of policy-induced changes in production and credit allocation. In the Pigouvian carbon tax benchmark introduced below, this assumption is relaxed by allowing sectoral emissions to enter firms' effective production costs through a carbon tax. The tax applies to emissions from both green and brown sectors, but it imposes a larger unit cost on brown production because brown firms are more emissions-intensive.

The following subsections present the optimization problems for households, production sectors, capital producers, firms with loan demand, banks, the central bank, and the fiscal authority. Detailed derivations are provided in the Appendix.

We present the optimization problems encountered by households, retailers, wholesalers, firms, banks, the government, and the capital sector within the model, with detailed calculations provided in the Appendix. Under reasonable parameter settings, all policy tools promote lending for low-carbon projects, with refinancing policy proving to be the most effective instrument.

2.2. Household sector

The economy is populated by a representative household. The household supplies homogeneous labour, consumes the final good, holds real money balances, and saves through deposits at financial intermediaries. The household also owns productive firms, banks, and capital producers, and receives their profits as dividends. Let C_t denote real consumption, M_t/P_t real money balances, L_t labour supply, and D_t real deposits carried from period t to $t+1$. The final-good price is denoted by P_t. The parameter $\beta \in (0,1)$ is the discount factor. The parameters σ_c and σ_m govern the curvature of utility from consumption and real money balances, respectively, while σ_l is the inverse Frisch elasticity of labour supply. The risk-free gross real return on deposits is denoted by r_t. It is defined as the expected gross nominal deposit rate adjusted for expected inflation: $r_t \equiv E_t\left(\frac{i_t}{\pi_{t+1}}\right)$, where i_t is the gross nominal deposit rate between t and $t+1$, and $\pi_{t+1} = P_{t+1}/P_t$ is gross inflation. In the household budget constraint, $r_{t-1}D_{t-1}$ denotes the realized real return on deposits carried from $t-1$ to t. Finally, T_t denotes lump-sum taxes, and PRO_t denotes aggregate real profits rebated to the household.

Accordingly, the representative household chooses $\{C_{t+k}, M_{t+k}, L_{t+k}, D_{t+k}\}_{k=0}^{\infty}$ to maximize:

$$\max_{\{C_{t+k}, M_{t+k}, L_{t+k}, D_{t+k}\}_{k=0}^{\infty}} E_t \sum_{k=0}^{\infty} \beta^k \left[\frac{C_{t+k}^{1-\sigma_c}}{1-\sigma_c} + \zeta \frac{\left(\frac{M_{t+k}}{P_{t+k}}\right)^{1-\sigma_m}}{1-\sigma_m} - \xi \frac{L_{t+k}^{1+\sigma_l}}{1+\sigma_l} \right] \tag{1}$$

subject to the budget constraint:

$$C_t + \frac{(M_t - M_{t-1})}{P_t} + D_t = \frac{W_t}{P_t} L_t - T_t + r_{t-1} D_{t-1} + PRO_t \tag{2}$$

Labor supply equation:

$$\xi L_t^{\sigma_l} = \frac{W_t}{P_t} C_t^{-\sigma_c} \tag{3}$$

Euler equation for deposit holdings:

$$1 = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} r_t \right) \tag{4}$$

Money demand equation:

$$\left(\frac{M_t}{P_t}\right)^{\sigma_m} = \zeta \left(\frac{r_t}{r_t - 1}\right) C_t^{\sigma_c} \tag{5}$$

Lagrange multiplier λ_t:

$$\lambda_t = C_t^{-\sigma_c} \tag{6}$$

where λ_t represents the marginal utility of consumption and can also be interpreted as the shadow value of relaxing the household budget constraint. Eq. (3) equates the marginal disutility of labour to the real wage multiplied by the marginal utility of consumption. Eq. (4) is written in terms of the expected gross real return on deposits, r_t, which incorporates expected inflation between $t$and $t+1$. Eq. (5) reflects the opportunity cost of holding real money balances rather than interest-bearing deposits.

2.3. Aggregation and price setting

This section describes the aggregation of differentiated green and brown varieties and the price-setting problem. To avoid confusion, we distinguish between three layers of production. First, within each sector $i \in \{g, b\}$, a continuum of monopolistically competitive firms $j \in [0, 1]$ produces differentiated varieties $Y_{i,t}^j$. These varieties are aggregated into a composite sectoral good $Y_{i,t}$. Second, the composite green good $Y_{g,t}$ and composite brown good $Y_{b,t}$ are combined into the aggregate final good Y_t. Third, nominal rigidity is introduced at the level of differentiated green and brown producers through Calvo price setting. The sectoral aggregators and the final-good producer are competitive and take prices as given. For each sector $i \in \{g, b\}$, following Dixit and Stiglitz (1977), differentiated varieties are aggregated as follows:

$$Y_{i,t} = \left[\int_0^1 {Y_{i,t}^j}^{(\epsilon_p - 1)/\epsilon_p} dj \right]^{\epsilon_p/(\epsilon_p - 1)} \tag{7}$$

where $\epsilon_p > 1$ is the elasticity of substitution across differentiated varieties within each sector. The corresponding sectoral price index is:

$$P_{i,t} = \left[\int_0^1 {P_{i,t}^j}^{(1-\epsilon_p)} dj \right]^{1/(1-\epsilon_p)} \tag{8}$$

The competitive sectoral aggregator chooses $\left\{ Y_{i,t}^j \right\}$ to maximize profits, taking prices as given:

$$\max_{\left\{ Y_{i,t}^j \right\}_{j \in [0,1]}} P_{i,t} Y_{i,t} - \int_0^1 P_{i,t}^j Y_{i,t}^j \, dj \tag{9}$$

subject to

$$Y_{i,t} = \left[\int_0^1 {Y_{i,t}^j}^{(\epsilon_p - 1)/\epsilon_p} dj \right]^{\epsilon_p/(\epsilon_p - 1)} \tag{10}$$

The demand for each differentiated variety is:

$$Y_{i,t}^{j} = \left(\frac{P_{i,t}^{j}}{P_{i,t}}\right)^{-\epsilon_p} Y_{i,t} \tag{11}$$

Eq. (11) shows that demand for each differentiated variety is decreasing in its relative price. Under perfect competition among aggregators, zero profit implies:

$$P_{i,t}Y_{i,t} = \int_0^1 P_{i,t}^{j} Y_{i,t}^{j}\, dj \tag{12}$$

The composite green and brown goods are then combined by a competitive final-good producer. Aggregate final output is given by:

$$Y_t = \left[(\varphi)^{\frac{1}{\chi}}\left(Y_{g,t}\right)^{\frac{\chi-1}{\chi}} + (1-\varphi)^{\frac{1}{\chi}}\left(Y_{b,t}\right)^{\frac{\chi-1}{\chi}}\right]^{\frac{\chi}{\chi-1}} \tag{13}$$

where φ is the weight of green goods and χ is the elasticity of substitution between green and brown goods. The corresponding aggregate price index is:

$$P_t = \left[\varphi\left(P_{g,t}\right)^{1-\chi} + (1-\varphi)\left(P_{b,t}\right)^{1-\chi}\right]^{\frac{1}{1-\chi}} \tag{14}$$

The final-good producer chooses $Y_{g,t}$ and $Y_{b,t}$ to maximize output subject to the expenditure constraint:

$$\max_{Y_{g,t},Y_{b,t}} \left[(\varphi)^{\frac{1}{\chi}}\left(Y_{g,t}\right)^{\frac{\chi-1}{\chi}} + (1-\varphi)^{\frac{1}{\chi}}\left(Y_{b,t}\right)^{\frac{\chi-1}{\chi}}\right]^{\frac{\chi}{\chi-1}} \tag{15}$$

subject to

$$P_{g,t}Y_{g,t} + P_{b,t}Y_{b,t} = P_tY_t \tag{16}$$

The resulting demand functions for green and brown composite goods are:

$$Y_{g,t} = (\varphi)\left(\frac{P_{g,t}}{P_t}\right)^{-\chi} Y_t \tag{17}$$

$$Y_{b,t} = (1-\varphi)\left(\frac{P_{b,t}}{P_t}\right)^{-\chi} Y_t \tag{18}$$

We now introduce nominal rigidity. Following Calvo (1983), differentiated green and brown producers can reset prices in a given period with probability $1-\theta_p$, while a fraction θ_p keeps prices unchanged. Let P_t^* denote the optimal reset price, and define $\pi_t^* = P_t^*/P_t$. Price dispersion is denoted by d_t^P, and evolves according to:

$$d_t^P = \left(1-\theta_p\right)\left(\pi_t^*\right)^{-\epsilon_p} + \theta_p\pi_t^{\epsilon_p} d_{t-1}^P \tag{19}$$

Price dispersion creates an efficiency loss, so aggregate output satisfies:

$$Y_t = d_t^P Y_t^f \tag{20}$$

The Calvo price index is:

$$1 = \left(1-\theta_p\right)\left(\pi_t^*\right)^{\left(1-\epsilon_p\right)} + \theta_p(\pi_t)^{\left(\epsilon_p-1\right)} \tag{21}$$

A producer that is allowed to reset its price chooses P_t^* to maximize the expected discounted value of profits subject to the demand for its variety:

$$\max_{P_t^*} E_t\left[\sum_{s=0}^{\infty}\left(\beta\theta_p\right)^s \Lambda_{t,t+s}\left(P_t/P_{t+s}\right)\left(P_t^* - MC_{t+s}^n\right)\right] Y_{t+s} \tag{22}$$

where MC_{t+s}^n denotes the nominal marginal cost of production and $\Lambda_{t,t+s}$ is the household stochastic discount factor. The optimal reset price can be written as:

$$\frac{P_t^*}{P_t} = \frac{\epsilon_p}{\epsilon_p - 1}\frac{f_t^1}{f_t^2} \tag{23}$$

where

$$f_t^1 = \lambda_t mc_t Y_t + \beta\theta_p E_t \pi_{t+1}^{\epsilon_p} f_{t+1}^1 \tag{24}$$

$$f_t^2 = \lambda_t Y_t + \beta\theta_p E_t \pi_{t+1}^{\epsilon_p - 1} f_{t+1}^2 \tag{25}$$

and

$$mc_t = MC_t^n / P_t \tag{26}$$

is real marginal cost. Eqs. (23)–(26) summarize the standard New Keynesian price-setting block implied by Calvo pricing.

2.4. Sectoral production, technology, and carbon emissions

In this section, we describe sectoral production, technology, and emissions. The production functions apply at the level of individual differentiated producers. Let $Y_{i,t}^j$ denote the output of firm j in sector $i \in \{g, b\}$, where g denotes the green sector and b denotes the brown sector. Variables without the firm index j, such as $Y_{i,t}$, denote sectoral aggregates under symmetric equilibrium. This notation links the production block to the aggregation structure described in Section 2.3.

Green and brown firms hire labour from households and rent capital services from capital producers. They do not own the aggregate capital stock directly. Capital producers own installed capital, choose investment, and rent capital to productive firms at the rental rate $R_{i,t}^k$. This separation ensures that the production decision of green and brown firms is distinct from the capital-accumulation decision of capital producers.

For green firms, production is given by the Cobb-Douglas technology:

$$Y_{g,t}^j = A_{g,t}\left(K_{g,t}^j\right)^{\alpha_g}\left(L_{g,t}^j\right)^{1-\alpha_g} \tag{27}$$

where $A_{g,t}$ is green-sector technology, $K_{g,t}^j$ is capital rented by green firm j, and $L_{g,t}^j$ is labour hired by green firm j. Under symmetric equilibrium within the green sector, $Y_{g,t}^j = Y_{g,t}$, $K_{g,t}^j = K_{g,t}$, and $L_{g,t}^j = L_{g,t}$. Green-sector emissions are defined as:

$$CE_{g,t} = \frac{\theta_{ge}}{A_{g,t}} Y_{g,t} \tag{28}$$

where θ_{ge} is the green-sector emissions coefficient. Emissions increase with output and decline with technology, so technological improvement reduces emissions per unit of output. The labour-demand condition for green firms is:

$$L_{g,t} = (1-\alpha_g) mc_{g,t} \frac{Y_{g,t}}{W_{g,t}} \tag{29}$$

where $mc_{g,t}$ denotes the pre-tax real marginal cost of green production and $W_{g,t}$ is the real wage paid by green firms. The expected return on green capital is:

$$E_t\left\{R_{g,t+1}^k\right\} = E_t\left[\alpha_g mc_{g,t+1}\frac{Y_{g,t+1}}{K_{g,t}} + Q_{t+1}(1-\delta)\right] \Big/ Q_t \tag{30}$$

The nominal marginal cost of green production is related to real marginal cost by:

$$MC_{g,t}^n = P_t mc_{g,t} \tag{31}$$

where P_t is the aggregate final-good price index. Equivalently, $mc_{g,t} = MC_{g,t}^n / P_t$. Under the Pigouvian carbon tax benchmark introduced below, the corresponding tax-inclusive real marginal cost is denoted by $mc_{g,t}^\tau$, and the tax-inclusive nominal marginal cost is $P_t mc_{g,t}^\tau$.

The brown sector is defined analogously. Brown firms produce according to:

$$Y_{b,t}^j = A_{b,t}\left(K_{b,t}^j\right)^{\alpha_b}\left(L_{b,t}^j\right)^{1-\alpha_b} \tag{32}$$

where $A_{b,t}$ is brown-sector technology. Under symmetric equilibrium, firm-level variables aggregate to $Y_{b,t}$, $K_{b,t}$, and $L_{b,t}$.

Brown-sector emissions are:

$$CE_{b,t} = \frac{\theta_{be}}{A_{b,t}} Y_{b,t} \tag{33}$$

where θ_{be} is the brown-sector emissions coefficient. Since brown production is more carbon-intensive, θ_{be} is assumed to exceed θ_{ge}.

The labour-demand condition for brown firms is:

$$L_{b,t} = (1-\alpha_b) mc_{b,t} \frac{Y_{b,t}}{W_{b,t}} \tag{34}$$

where $mc_{b,t}$ denotes the pre-tax real marginal cost of brown production. The expected return on brown capital is:

$$E_t\left(R^k_{b,t+1}\right) = E_t\left[\frac{\alpha_b mc_{b,t+1} Y_{b,t+1}/K_{b,t} + Q_{t+1}(1-\delta)}{Q_t}\right] \tag{35}$$

The nominal marginal cost of brown production is related to the pre-tax real marginal cost by:

$$MC^n_{b,t} = P_t mc_{b,t} \tag{36}$$

Under the Pigouvian carbon tax benchmark introduced below, the corresponding tax-inclusive real marginal cost is denoted by $mc^{\tau}_{b,t}$, and the tax-inclusive nominal marginal cost is $P_t mc^{\tau}_{b,t}$. Sectoral capital and labour are obtained by aggregating across firms and sectors:

$$K_t = K_{g,t} + K_{b,t} \tag{37}$$

$$L_t = L_{g,t} + L_{b,t} \tag{38}$$

Labour is homogeneous and perfectly mobile across sectors, implying a common wage across sectors:

$$W_t = W_{g,t} = W_{b,t} \tag{39}$$

In the baseline model, emissions are treated as an unpriced negative externality. They do not directly enter household utility or the production costs of firms. Instead, emissions are computed from sectoral output and technology and are used to evaluate the environmental consequences of policy-induced changes in production and credit allocation.

To provide a benchmark for comparison with the finance-based policy instruments, we also introduce a Pigouvian carbon tax on sectoral emissions. The tax applies to emissions from both green and brown sectors, but the effective tax burden differs across sectors because green production has a lower emissions intensity. Let τ^e_t denote the real carbon tax rate, measured in units of the final good per unit of emissions. Aggregate emissions are: $CE_t = CE_{g,t} + CE_{b,t}$. Total carbon tax revenue is given by:

$$T^e_t = \tau^e_t CE_t \tag{40}$$

Using Eqs. (28) and (33), sectoral tax payments can be written as:

$$T^e_{g,t} = \tau^e_t \frac{\theta_{ge}}{A_{g,t}} Y_{g,t}, T^e_{b,t} = \tau^e_t \frac{\theta_{be}}{A_{b,t}} Y_{b,t}$$

Because $\theta_{be} > \theta_{ge}$, the brown sector faces a larger carbon tax burden per unit of output than the green sector. The Pigouvian carbon tax therefore increases the effective marginal cost of production in both sectors, but the increase is smaller for green firms:

$$mc^{\tau}_{g,t} = mc_{g,t} + \tau^e_t \frac{\theta_{ge}}{A_{g,t}}, mc^{\tau}_{b,t} = mc_{b,t} + \tau^e_t \frac{\theta_{be}}{A_{b,t}} \tag{41}$$

When the Pigouvian carbon tax benchmark is considered, $mc_{g,t}$and $mc_{b,t}$in the sectoral optimality conditions are replaced by $mc^{\tau}_{g,t}$ and $mc^{\tau}_{b,t}$, respectively. In the baseline financial-policy experiments, $\tau^e_t = 0$, so $mc^{\tau}_{g,t} = mc_{g,t}$ and $mc^{\tau}_{b,t} = mc_{b,t}$. The tax revenue accrues to the fiscal authority and is used to finance public expenditure or rebated lump-sum to households, so that the benchmark isolates the allocative effect of carbon pricing. This benchmark captures the standard Pigouvian mechanism: direct carbon pricing raises the effective cost of emissions-intensive production. Unlike the financial instruments studied in the baseline model, which operate indirectly through bank funding costs, credit spreads, leverage, and the external finance premium, the Pigouvian carbon tax works directly through the sectoral production-cost margin. This distinction is important because the tax generates a permanent change in relative sectoral costs and therefore provides a long-run benchmark against which the transitional effects of green credit policy, reserve requirements, and soft-budget-constraint policies can be compared.

2.5. Capital sector

Capital producers own installed capital, choose investment, and rent capital services to green and brown firms. They purchase the final good and transform it into new physical capital subject to convex investment adjustment costs. Green and brown firms do not own the aggregate capital stock directly; instead, they rent capital services from capital producers at competitive rental rates. This timing separates the capital-accumulation decision from the production decision described in Section 2.4. Rental payments from green and brown firms determine the equilibrium return on installed capital, while the capital producer's investment decision determines the law of motion for aggregate capital. The capital producer chooses the sequence $\{I_{t+s}, K_{t+s}\}_{s=0}^{\infty}$ to maximize the expected discounted value of profits:

$$\max_{\{I_{t+s},K_{t+s}\}_{s=0}^{\infty}} E_t \sum_{s=0}^{\infty} \beta^s \Lambda_{t,t+s} \left\{ Q_{t+s} \left[1 - \Psi\left(\frac{I_{t+s}}{I_{t+s-1}} \right) \right] - 1 \right\} I_{t+s} \tag{42}$$

subject to the capital-accumulation equation:

$$K_t = (1-\delta)K_{t-1} + \left[1 - \frac{\psi_1}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] I_t \tag{43}$$

where the investment adjustment cost is:

$$\Psi\left(\frac{I_t}{I_{t-1}} \right) = \frac{\psi_1}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \tag{44}$$

Here I_t denotes investment in units of the final good, Q_t is the real price of installed capital, δ is the depreciation rate, and ψ_1 governs the size of investment adjustment costs. The stochastic discount factor is given by: $\Lambda_{t,t+s} = \lambda_{t+s}/\lambda_t$.

The convex adjustment cost implies that rapid changes in investment are costly and helps ensure an interior investment decision. The first-order condition for investment is:

$$Q_t \left[1 - \frac{\psi_1}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 - \psi_1 \left(\frac{I_t}{I_{t-1}} - 1 \right) \frac{I_t}{I_{t-1}} \right] + \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \psi_1 \left(\frac{I_{t+1}}{I_t} - 1 \right) \left(\frac{I_{t+1}}{I_t} \right)^2 Q_{t+1} = 1 \tag{45}$$

2.6. Firms with loan demand

To examine the financing problem of green and brown firms, we follow the costly state verification framework of Bernanke et al. (1999). In the BGG structure, firms finance capital partly with internal net worth and partly with external bank loans. Because realized capital returns are subject to idiosyncratic firm-level shocks, external finance is costly and the external finance premium increases with firm leverage.

It is important to distinguish the BGG return shock from the sectoral technology processes introduced in the production block. The sectoral technology variables $A_{g,t}$ and $A_{b,t}$ affect production efficiency and emissions intensity. By contrast, $\omega_{g,t+1}$ and $\omega_{b,t+1}$ are idiosyncratic ex post return shocks in the loan-contracting problem. They determine realized capital returns, default outcomes, monitoring costs, and the external finance premium. Since there is a continuum of firms, idiosyncratic shocks average out in aggregate quantities, but their distribution affects equilibrium loan rates through default probabilities and expected monitoring costs.

For sector $i \in \{g, b\}$, firm assets are composed of net worth and bank loans:

$$Q_t K_{i,t} = N_{i,t} + B_{i,t} \tag{46}$$

where $Q_t K_{i,t}$ is the value of capital, $N_{i,t}$ is firm net worth, and $B_{i,t}$ denotes bank borrowing. The leverage ratio is:

$$LEV_{i,t} = Q_t K_{i,t} / N_{i,t} \tag{47}$$

For green firms, the realized return on capital in period $t+1$ is $\omega_{g,t+1} R^k_{g,t+1}$, where $R^k_{g,t+1}$ is the average return on green capital and $\omega_{g,t+1}$ is an idiosyncratic return shock. The default threshold is denoted by $\bar{\omega}_{g,t+1}$. Firms with $\omega_{g,t+1} \geq \bar{\omega}_{g,t+1}$ repay their loans, while firms with $\omega_{g,t+1} < \bar{\omega}_{g,t+1}$ default.

We assume that the fiscal authority provides a partial and capped guarantee for eligible green loans. Let G_{t+1} denote the guarantee payment, and define the guaranteed share of green capital income as:

$$g_{t+1} = \frac{G_{t+1}}{R^k_{g,t+1} Q_t K_{g,t}} \tag{48}$$

The guarantee is partial and bounded, with $g_{t+1} \in [0, \bar{g}]$ and $\bar{g} < 1$. It applies only to eligible green loans and does not cover the entire repayment obligation. It therefore reduces, but does not eliminate, expected default losses. Firms and banks continue to bear residual risk, and the external finance premium remains increasing in leverage. This assumption rules out unlimited borrowing and preserves an interior optimal contract.

The non-default loan rate on green debt is $R^l_{g,t+1}$, and the default threshold satisfies:

$$G_{t+1} + \bar{\omega}_{g,t+1} R^k_{g,t+1} Q_t K_{g,t} = R^l_{g,t+1} B_{g,t} \tag{49}$$

If $\omega_{g,t+1} \geq \bar{\omega}_{g,t+1}$, the green firm repays $R^l_{g,t+1} B_{g,t}$, and the residual return accrues to the firm. If $\omega_{g,t+1} < \bar{\omega}_{g,t+1}$, the firm defaults. In that case, the lender receives the guarantee payment plus the recoverable value of the firm's capital after monitoring costs. Monitoring costs are proportional to realized capital returns and are governed by the parameter τ. The parameter τ is a monitoring-cost parameter and should not be confused with the Pigouvian carbon tax rate τ^e_t introduced in Section 2.4.

Financial institutions are competitive, so the expected return on green loans must equal lenders' opportunity cost of funds. The

opportunity cost is denoted by i_{t+1}, which represents the gross risk-free return realized at $t+1$ on funds lent at t:

$$\left[1-F_g\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)\right]R^l_{g,t+1}B_{g,t}+\int_0^{\overline{\omega}_{g,t+1}}\left[G_{t+1}+(1-\tau)\omega_g R^k_{g,t+1}Q_tK_{g,t}\right]dF_g\left(\omega_g,\sigma_{\omega g}\right)=i_{t+1}B_{g,t} \tag{50}$$

The debt contract between green firms and financial institutions chooses leverage and the default threshold to maximize the expected payoff of green firms:

$$\max_{LEV_{g,t},\overline{\omega}_{g,t+1}} E_t\left[1-\Gamma\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)-g_{t+1}\right]R^k_{g,t+1}Q_tK_{g,t} \tag{51}$$

subject to:

$$\left[\Gamma\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)-\tau G_{\omega,g}\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)+g_{t+1}\right]R^k_{g,t+1}Q_tK_{g,t}=i_{t+1}\left(Q_tK_{g,t}-N_{g,t}\right) \tag{52}$$

where

$$\Gamma\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)=\overline{\omega}_{g,t+1}\left(1-F_g\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)\right)+G_{\omega,g}\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right) \tag{53}$$

and

$$G_{\omega,g}\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)=\int_0^{\overline{\omega}_{g,t+1}}\omega_g dF_g\left(\omega_g,\sigma_{\omega g}\right) \tag{54}$$

The partial guarantee lowers the expected default-loss component of green lending and therefore reduces the external finance premium faced by green firms. However, because the guarantee is partial and capped, it does not remove default risk entirely. As a result, green firms still face an increasing financing premium as leverage rises.

The relationship between the expected return on capital and green-firm leverage is:

$$\left[1-\Gamma\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)-g_{t+1}\right]\frac{R^k_{g,t+1}}{i_{t+1}}=\frac{1}{LEV_{g,t}}\frac{1-F_g\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)}{1-F_g\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)-\tau\overline{\omega}_{g,t+1}F_{\omega,g}\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)} \tag{55}$$

If γ_g is the survival rate of green firms, then green firms' net worth evolves according to:

$$N_{g,t}=\gamma_g\left[R^k_{g,t}Q_{t-1}K_{g,t-1}\left(1-\tau G_{\omega,g}\left(\overline{\omega}_{g,t},\sigma_{\omega g}\right)+g_t\right)-i_tB_{g,t-1}\right] \tag{56}$$

The guarantee share follows an exogenous process:

$$\log g_t=\left(1-\rho_g\right)\log g_{ss}+\rho_g\log g_{t-1}+\varepsilon^g_t,\quad \varepsilon^g_t\sim N\left(0,{\sigma_g}^2\right) \tag{57}$$

where the subscript ss denotes the steady state. In the quantitative analysis, g_t is restricted to remain below the upper bound $\bar{g}<1$, consistent with the assumption of a partial and capped guarantee.

The brown-sector contract is analogous, except that brown firms do not receive government loan guarantees. The default threshold for brown firms satisfies:

$$\overline{\omega}_{b,t+1}R^k_{b,t+1}Q_tK_{b,t}=R^l_{b,t+1}B_{b,t} \tag{58}$$

The zero-profit condition for brown lenders is:

$$\left[1-F_b(\overline{\omega}_{b,t+1},\sigma_{\omega b})\right]R^l_{b,t+1}B_{b,t}+\int_0^{\overline{\omega}_{b,t+1}}\left[(1-\tau)\omega_b R^k_{b,t+1}Q_tK_{b,t}\right]dF_b(\omega_b,\sigma_{\omega b})=i_{t+1}B_{b,t} \tag{59}$$

The brown-firm debt contract is:

$$\max_{LEV_{b,t},\overline{\omega}_{b,t+1}} E_t\left[1-\Gamma\left(\overline{\omega}_{b,t+1},\sigma_{\omega b}\right)\right]R^k_{b,t+1}Q_tK_{b,t} \tag{60}$$

where the brown-sector expected repayment function is defined as: $\Gamma(\bar{\omega}_{b,t+1},\sigma_{\omega b})=\bar{\omega}_{b,t+1}\left[1-F_b(\bar{\omega}_{b,t+1},\sigma_{\omega b})\right]+G_{\omega,b}(\bar{\omega}_{b,t+1},\sigma_{\omega b})$, and the truncated first moment of the brown-sector idiosyncratic return shock is: $G_{\omega,b}(\bar{\omega}_{b,t+1},\sigma_{\omega b})=\int_0^{\bar{\omega}_{b,t+1}}\omega_b dF_b(\omega_b,\sigma_{\omega b})$.

Here, $F_b(\cdot)$ denotes the distribution function of the brown-sector idiosyncratic return shock. These definitions are sector-specific and are analogous to the green-sector definitions above. They allow the distributions of ω_g and ω_b to differ across sectors.

The brown-sector lender zero-profit constraint can therefore be written as:

$$\left[\Gamma(\overline{\omega}_{b,t+1},\sigma_{\omega b})-\tau G_{\omega,b}\left(\overline{\omega}_{b,t+1},\sigma_{\omega b}\right)\right]R^k_{b,t+1}Q_tK_{b,t}=i_{t+1}(Q_tK_{b,t}-N_{b,t}) \tag{61}$$

The relationship between the expected return on brown capital and brown-firm leverage is:

$$\left[1-\Gamma\left(\overline{\omega}_{b,t+1},\sigma_{\omega b}\right)\right]\frac{R^k_{b,t+1}}{i_{t+1}}=\frac{1}{LEV_{b,t}}\,\frac{1-F_b\left(\overline{\omega}_{b,t+1},\sigma_{\omega b}\right)}{1-F_b\left(\overline{\omega}_{b,t+1},\sigma_{\omega b}\right)-\tau\overline{\omega}_{b,t+1}F_{\omega,b}\left(\overline{\omega}_{b,t+1},\sigma_{\omega b}\right)} \tag{62}$$

Brown firms' net worth evolves according to:

$$N_{b,t}=\gamma_b\left[R^k_{b,t}Q_{t-1}K_{b,t-1}\left(1-\tau G_{\omega,b}\left(\overline{\omega}_{b,t},\sigma_{\omega b}\right)\right)-i_tB_{b,t-1}\right] \tag{63}$$

2.7. Banking sector

Banks intermediate funds between households and the production sectors described above. They collect deposits from households and extend loans to firms. For tractability, banks are differentiated by loan portfolio rather than by institutional type. Green-lending banks provide loans only to green firms, while brown-lending banks provide loans only to brown firms. This classification captures green and brown credit exposures and should not be interpreted as a literal institutional separation of banks.

Following Gerali et al. (2010), each type of bank is represented by a continuum of differentiated lenders of measure one. Firms in sector $i\in\{g,b\}$ combine differentiated loans $B^j_{i,t}$ into a composite loan $B_{i,t}$:

$$\left[\int_0^1\left(B^j_{i,t}\right)^{\frac{\kappa-1}{\kappa}}dj\right]^{\frac{\kappa}{\kappa-1}}\geq B_{i,t} \tag{64}$$

where $\kappa>1$ is the elasticity of substitution across differentiated bank loans. The corresponding loan-rate index is:

$$R^l_{i,t}=\left[\int_0^1\left(R^{l,j}_{i,t}\right)^{1-\kappa}dj\right]^{\frac{1}{1-\kappa}} \tag{65}$$

Cost minimization by firms implies the demand for loans from bank j:

$$B^j_{i,t}=\left(\frac{R^{l,j}_{i,t}}{R^l_{i,t}}\right)^{-\frac{\kappa}{\kappa-1}}B_{i,t} \tag{66}$$

Banks are subject to reserve requirements. Let R^r_t denote the reserve requirement ratio. Green-lending banks finance green loans using household deposits and targeted refinancing from the central bank. Their balance-sheet constraint is:

$$B_{g,t}+R^r_tB_{g,t}=D_{g,t}+H_{g,t} \tag{67}$$

where $D_{g,t}$ denotes deposits held by green-lending banks and $H_{g,t}$ denotes targeted central-bank refinancing. Green-lending banks choose loans, deposits, and refinancing to maximize expected discounted profits:

$$\max_{\left\{B_{g,t+s},D_{g,t+s},H_{g,t+s}\right\}_{s=0}^{\infty}}E_t\sum_{s=0}^{\infty}\beta^s\left[\left(1-o_g\right)R^l_{g,t+s}B_{g,t+s}-i_{t+s}D_{g,t+s}-R^h_{g,t+s}H_{g,t+s}-Adcost_{g,t+s}\right] \tag{68}$$

subject to

$$Adcost_{g,t}=\frac{\psi_2}{2}\left(\frac{B_{g,t}}{B_{g,t-1}}-1\right)^2B_{g,t}+\frac{\psi_3}{2}\left(\frac{D_{g,t}}{D_{g,t-1}}-1\right)^2D_{g,t}+\frac{\psi_4}{2}\left(\frac{H_{g,t}}{H_{g,t-1}}-1\right)^2H_{g,t} \tag{69}$$

$$B_{g,t}=\left(1-R^r_t\right)D_{g,t}+H_{g,t} \tag{70}$$

and

$$H_{g,t}\leq\varpi_tB_{g,t} \tag{71}$$

Here $B_{g,t}$ represents loans extended by green-lending banks to green firms, $R^l_{g,t}$ is the green loan rate, and o_g is the non-performing loan ratio. Banks pay the gross risk-free deposit rate i_t to households. The central bank provides targeted refinancing $H_{g,t}$ at the refinancing rate $R^h_{g,t}$. The refinancing ceiling is governed by the pledge ratio ϖ_t. When the refinancing constraint binds, $H_{g,t}=\varpi_tB_{g,t}$. The preferential refinancing rate $R^h_{g,t}$ lowers the funding cost of green-lending banks and is transmitted to green firms through the loan rate $R^l_{g,t}$.

Brown-lending banks are defined analogously, except that they do not receive targeted refinancing from the central bank. They finance brown loans only through household deposits subject to reserve requirements. Their balance-sheet constraint is:

$$B_{b,t}=\left(1-R^r_t\right)D_{b,t} \tag{72}$$

Brown-lending banks choose loans and deposits to maximize:

$$\max_{\{B_{b,t+s},D_{b,t+s}\}_{s=0}^{\infty}} E_t \sum_{s=0}^{\infty} \beta^s \left[(1-o_b) R^l_{b,t+s} B_{b,t+s} - i_{t+s} D_{b,t+s} - Adcost_{b,t+s} \right] \tag{73}$$

subject to

$$Adcost_{b,t} = \frac{\psi_5}{2} \left(\frac{B_{b,t}}{B_{b,t-1}} - 1 \right)^2 B_{b,t} + \frac{\psi_6}{2} \left(\frac{D_{b,t}}{D_{b,t-1}} - 1 \right)^2 D_{b,t} \tag{74}$$

The key difference between the two banking blocks is therefore the access of green-lending banks to targeted central-bank refinancing. Reserve requirements affect both types of banks through the common liquidity channel, whereas targeted refinancing affects only the funding cost of green credit.

2.8. The central bank and government

The central bank has two monetary policy tools. The first is a conventional reserve-requirement policy that affects bank liquidity. The second is a targeted refinancing facility through which green-lending banks can obtain central-bank funding against eligible collateral. The fiscal authority provides government spending and partial loan guarantees for eligible green loans. In addition, the Pigouvian carbon tax benchmark introduced in Section 2.4 allows the fiscal authority to tax sectoral emissions. Since brown production has higher emissions intensity, the same emissions tax generates a larger effective unit cost wedge for brown firms than for green firms.

2.8.1. Reserve requirements

The central bank adjusts the reserve requirement ratio in response to output and inflation developments:

$$\widehat{R}^r_t = \rho_r \widehat{R}^r_{t-1} + (1-\rho_r)(\phi_Y \widehat{Y}_t + \phi_\pi \widehat{\pi}_t) + \varepsilon^{R^r}_t \tag{75}$$

where all hatted variables denote deviations from steady state. The parameter ρ_r is the smoothing coefficient of the reserve requirement ratio, while ϕ_Y and ϕ_π measure the response of reserve requirements to output and inflation, respectively. The reserve-requirement shock is $\varepsilon^{R^r}_t \sim i.i.d.N(0, \sigma^2_{R^r})$.

2.8.2. Green credit finance from the central bank

The central bank also provides targeted refinancing to green-lending banks. This policy lowers the funding cost of banks that extend credit to green firms and is transmitted to green firms through the loan rate. The refinancing rate for green-lending banks is denoted by $R^h_{g,t}$. In log-linear form, the refinancing rule is:

$$\widehat{R}^h_{g,t} = \rho_h \widehat{R}^h_{g,t-1} + (1-\rho_h)\left[\widehat{i}_t - \mu_1 \left(\widehat{B}_{g,t} - \widehat{B}_{g,t-1}\right)\right] + \varepsilon^h_t \tag{76}$$

where $0 < \rho_h < 1$ is the smoothing parameter and $\varepsilon^h_t \sim N(0, \sigma^2_h)$.

2.8.3. Government budget and Pigouvian carbon tax benchmark

The fiscal authority finances government spending and green-loan guarantee payments using seigniorage, lump-sum taxes, and, in the Pigouvian carbon tax benchmark, carbon-tax revenue from aggregate sectoral emissions. The government budget constraint is:

$$Gov_t + G_{t+1} = \frac{M_t - M_{t-1}}{P_t} + T_t + T^e_t \tag{77}$$

where Gov_t is government spending, G_{t+1} is the partial guarantee payment for eligible green loans, T_t denotes lump-sum taxes, and T^e_t is Pigouvian carbon tax revenue. In the baseline financial-policy experiments, $\tau^e_t = 0$, so $T^e_t = 0$. In the Pigouvian carbon tax benchmark, $\tau^e_t > 0$, and the tax revenue accrues to the fiscal authority. Government spending is specified as:

$$Gov_t = \psi_7 Y^f_t \tag{78}$$

The Pigouvian carbon tax benchmark is not treated as a fourth dynamic policy shock in the impulse-response analysis. Instead, it provides a steady-state benchmark for comparing direct carbon pricing with finance-based policy instruments. A permanent emissions tax raises the effective marginal cost of brown production, whereas reserve requirements, targeted refinancing, and loan guarantees operate through bank liquidity, funding costs, and default-risk premia. Lump-sum taxes and Pigouvian carbon tax revenues do not enter the aggregate resource constraint because they are transfers rather than uses of real resources.

2.9. Market clearing

The economy must achieve general equilibrium with labour, capital, goods, and credit markets clearing simultaneously. The aggregate resource constraint is:

$$Y_t^f = C_t + Gov_t + G_{t+1} + I_t + \tau G_\omega\left(\overline{\omega}_{g,t+1}, \sigma_{\omega g}\right) R_{g,t+1}^k Q_t K_{g,t} + \tau G_\omega\left(\overline{\omega}_{b,t+1}, \sigma_{\omega b}\right) R_{b,t+1}^k Q_t K_{b,t} \tag{79}$$

The last two terms are monitoring costs associated with default in the green and brown sectors. The function $G_\omega(\cdot)$ is the truncated first moment of the idiosyncratic BGG return shock, as defined in Section 2.6. In the Pigouvian carbon tax benchmark, the resource constraint is not altered by the tax revenue itself because emissions-tax revenue is a transfer from brown firms to the fiscal authority. In the Pigouvian carbon tax benchmark, the resource constraint is not altered by the tax revenue itself because carbon-tax revenue is a transfer from firms to the fiscal authority. The real allocation changes through the tax-inclusive sectoral marginal costs $mc_{g,t}^\tau$ and $mc_{b,t}^\tau$, defined in Section 2.4. Lump-sum taxes and Pigouvian carbon tax revenues do not appear in the aggregate resource constraint because they are transfers between private agents and the fiscal authority rather than uses of real resources.

As a form of direct carbon pricing, the Pigouvian carbon tax differs from the finance-based instruments studied in the baseline model. It directly raises the effective marginal cost of production according to sectoral carbon-emissions intensities. Since brown production is more carbon-intensive, the brown-sector cost wedge is larger than the green-sector cost wedge. By contrast, targeted refinancing and government guarantees lower the financing cost or expected default-loss component of green investment, while reserve requirements operate through aggregate bank liquidity.

3. Model calibration

We calibrate the parameters common in the New Keynesian literature to standard values, which we show in Table 1. Each phase in the model corresponds to a quarter in time. The household discount factor β set at 0.995 to match an annualized risk-free rate of 2%. The depreciation rate is set at $\delta = 0.025$ (Christiano et al., 2005; Foerster et al., 2011). The pledge rate for collateral to access the central bank's refinancing facility is capped at 70%. The ratio of government expenditure to GDP is set at $\psi_7 = 0.1$, which matches the share of private consumption in total output equal to 0.56 (Fagan et al., 2005). We choose a considerable amount of interest rate inertia $\rho_r = 0.8$, a moderate reaction to the output gap $\phi_Y = 0.125$, and a relatively strong reaction to inflation $\phi_\pi = 2$ (Justiniano et al., 2015). In the literature, the setting of elasticity of substitution by firms between intermediate goods ϵ_p is usually between 5 and 11, so we select a median value of 8 (Barsky et al., 2007).

Table 1
Calibrated Parameters.

Parameter	Description	Value
β	Discount factor	0.995
σ_c	Inverse of elasticity intertemporal substitution of consumption	2
σ_m	Inverse of elasticity intertemporal substitution of cash balance	1
σ_l	The inverse of the Frisch elasticity of labor supply	1
ζ	The share of real money balance in household utility	1
ξ	The share of labor supply in household utility	1.4084
α_g	Share of capital in production in green firms	0.33
α_b	Share of capital in production in brown firms	0.35
δ	Depreciation rate	0.025
θ_p	Price stickiness parameter	0.75
χ	Elasticity of substitution brown-green goods	0.8
ϵ_p	Elasticity of firms' substitution between intermediate goods	8
φ	Weight of green goods	0.5628
γ_g	Natural survival rate of green firms	0.9219
γ_b	Natural survival rate of brown firms	0.9864
τ	supervision costs	0.21
ϖ_t	Pledge rate	0.733
ψ_1	Investment adjustment cost	2.48
ψ_2	Adjustment cost of green firms' loan	2.47
ψ_3	Adjustment cost of green credit bank deposits	2.48
ψ_4	Adjustment cost of refinancing (green credit)	2.5
ψ_5	Adjustment cost of brown firms' loan	2.53
ψ_6	Adjustment cost of brown credit bank deposits	2.48
ψ_7	Ratio of government expenditure to GDP	0.1
ϕ_Y	Response coefficient of deposit rate to output gap	0.125
ϕ_π	Response coefficient of RRR to inflation gap	2
ρ_r	Smoothing coefficient of deposit reserve ratio	0.8
ρ_h	Smoothing coefficient of refinancing rate	0.33
ρ_ϖ	Smoothing coefficient of refinancing pledge rate	0.0536
ρ_{ga}	Persistence of technical impact of green firms	0.9583
ρ_{ba}	Persistence of technical impact of brown firms	0.7348

Generally, existing research assumes an elasticity of substitution between production inputs greater than 1. However, when examining substitution between brown and green goods χ, a lower elasticity - typically less than 1 - suggests significant challenges in transitioning from brown to green technologies, aligning more closely with real-world limitations (Acemoglu et al., 2012). In this study, we use 2 as a general benchmark and 0.8, which is below 1, to better capture these realistic constraints. Based on this insight, we explore various configurations of substitution elasticity between brown and green goods to assess its impact on technological transition dynamics. The investment adjustment cost elasticity is set at $\psi_1 = 2.48$ (Christiano et al., 2005). The parameter governing the degree of risk aversion of consumption is set at $\sigma_c = 2$, and the curvature of utility from real money balances is set at $\sigma_m = 1$. The inverse Frisch elasticity of labour supply is set to $\sigma_l = 1$ (Christiano et al., 2014), We choose a value of $\theta_p = 0.75$ for the Calvo parameter (Nakamura & Steinsson, 2008). We calibrate the share of labor supply in household utility as $\xi = 1.4084$, the weight of green goods as $\varphi = 0.5628$. We set the value of monitor cost as $\tau = 0.21$ (Christiano et al., 2014). We set the capital share in green production α_g is 0.33, the brown sector to be slightly more capital intensive, α_b is 0.35 (Carattini et al., 2023). The pledge rate is calculated by determining the ratio of pledged collateral to total assets under management (AUM). Specifically, as of the end of 2017, total pledged collateral from hedge funds amounted to USD 2.2 trillion, while their total AUM was USD 3.0 trillion (Singh & Goel, 2019). This results in a pledge rate ϖ_t of 73.3%. The response parameters of the refinancing rate to the proportion of green credit μ_1 and pledge rate to green industry credit ratio μ_2 are 0.4412 and 2.1309, respectively. The adjustment cost of green and brown firms' loans, bank deposits and refinancing are 2.47, 2.53, 2.48 and 2.5, respectively, which are close to the 2.5 (Kollmann, 2013).

The green and brown emissions coefficients are set to 0.1 and 0.5, respectively, implying that brown production is more emissions-intensive. For the Pigouvian carbon tax benchmark, we set 0.01. Finally, the smoothing coefficient of the refinancing rate, the pledge rate, and the persistence of technological development of green firms and brown firms are 0.33, 0.0536, 0.9583 and 0.7348, respectively.

4. Impulse response analysis

In this section, we examine the economic impact of two green monetary policy tools - reserve requirement policy and refinancing policy - along with government guarantees of green lending in response to a one-unit policy shock. We analyze how these policy instruments influence carbon emissions and firms' technology under varying substitution elasticities between green and brown products. Specifically, we assess how changes in the central bank's reserve requirement ratio and refinancing rate affect money and credit market yields, as well as how adjustments in the intensity of government loan guarantees alter lending behavior. These shifts will, in turn, lead to changes in the behavior and decisions of households, firms, and banks, ultimately influencing the trajectory toward climate goals and financial stability. We examine the economic impact of three policy instruments introduced earlier - the Reserve Requirement Ratio (RRR), the Green Credit Policy (GCP), and the Soft Budget Constraint (SBC) - which correspond respectively to (i) broad reserve requirements, (ii) bank refinancing targeted at supporting green lending, and (iii) fiscal support from government guarantees for green loans. These abbreviations (RRR, GCP, and SBC) are used hereafter in figures and subsequent discussions for brevity. The following subsections will provide a detailed examination of each policy shock, highlighting its distinct transmission mechanism and, crucially, distinguishing immediate (dynamic) from longer-term (steady-state) effects.

4.1. Policy shocks on carbon emissions and firm technology under different substitution elasticity between green and brown products

Substitution elasticity measures the substitutability between green and brown products. When elasticity is high (e.g., 2), green and brown products are more interchangeable, meaning that if green products become more cost-effective or technologically advanced, the market can quickly shift from brown to green. Conversely, when elasticity is below 1 (e.g., 0.8), substitution is weaker, implying a complementary relationship between green and brown products. In this case, even if green products improve, the market will not easily replace brown products, which restricts green firms' ability to technologically outperform brown firms and impacts emissions and technology evolution (see Acemoglu et al., 2012). In our framework, policy wedges operate primarily through two channels: (i) a relative user-cost of capital channel that changes financing conditions for green vs. brown projects, and (ii) a competitive reallocation channel whereby relative prices and credit spreads shift market shares. Investment adjustment costs and nominal rigidities then generate the familiar hump-shaped impulse responses.

As shown in Fig. 1, a reduction in reserve requirements injects liquidity into the market, broadly stimulating economic activity. Since this policy does not preferentially support green firms, brown firms equally benefit from increased credit access, resulting in a temporary rise in carbon emissions as output increases. When substitution elasticity is high, both green and brown firms experience lower borrowing costs. Given green firms' technological advantage, part of the market shifts quickly from brown to green. Initially, brown firms' technological levels may decrease slightly but later recover in response to intensified competition. When substitution elasticity is low, however, green and brown products are less interchangeable, limiting the policy's effectiveness. Even as borrowing costs fall, green products do not significantly replace brown ones, resulting in less pronounced market shifts toward green firms.

A green credit policy targets green firms by lowering their interest rates, reducing capital costs, and redirecting resources toward green firms. With high substitution elasticity, green products more readily replace brown products, leading to substantial technological improvements for green firms. While brown firms initially reduce technological investment due to shrinking market share, they eventually enhance technology to maintain competitiveness. When substitution elasticity is low, green firms still gain financing advantages, but the substitution effect on brown firms remains weak, limiting green firms' technological progress and reducing competitive pressure on brown firms to improve.

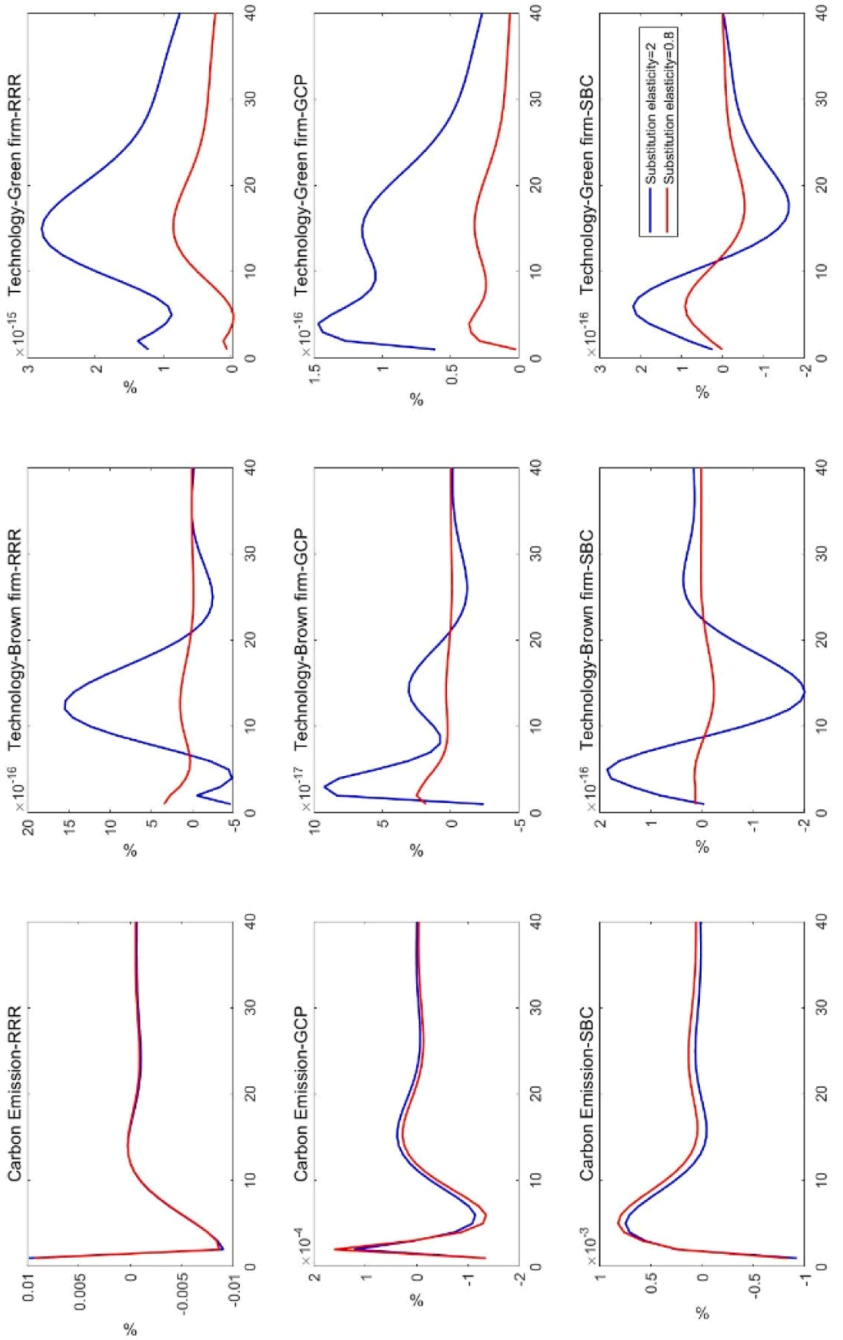


Fig. 1. Policy Shocks on Carbon Emissions and Firm Technology: The Role of Substitution Elasticity between Green and Brown Products.

Government guarantees of green loans lower financing costs and risks specifically for green firms, channeling fiscal resources toward green investments and innovation. Increased capital flow to green firms accelerates technological advancements, especially when green products are more substitutable for brown products. Initially, brown firms' technology may slightly decline, but they later advance significantly to meet green competition, resulting in reduced carbon emissions. When substitution elasticity is low, fiscal support still boosts green technology, but due to weaker substitution, demand does not significantly shift toward green products, limiting the technological response from brown firms.

Steady state. When $\sigma = 0.8$, the long-run reallocation toward green production is smaller for a given policy wedge: even if short-run responses move in the same direction, the economy converges to a greener steady state more slowly and with a higher residual share of brown output than under $\sigma = 2$. In our model, setting $\sigma < 1$ captures realistic substitution barriers between green and brown sectors and implies longer, costlier transitions: as the technology gap widens, the economy requires more time to converge to a low-emissions steady state. Thus, a low elasticity improves realism by reflecting resistance and delay costs in technological switching.

4.2. Effects of reserve requirement policy shocks

Fig. 2 demonstrates the impulse response analysis of a 1% reduction in the reserve requirement ratio on carbon emissions, credit spreads, loan volumes, firms' net assets, leverage, and capital returns. This policy shock generates a transmission mechanism across key economic variables, analyzed as follows:

A reduction in the reserve requirement ratio loosens liquidity constraints economy-wide, expanding credit and stimulating activity. Initially, the broad credit expansion raises overall investment and production across both sectors, leading to a temporary increase in carbon emissions. As green firms benefit from cheaper funding and higher production efficiency, the emission intensity of output declines, driving total emissions down. On impact, carbon emissions decline, then briefly overshoot the baseline as activity strengthens, and gradually converge thereafter. Because the tool is non-targeted, both sectors benefit from easier funding, but the improvement is asymmetric: the external-finance premium for green firms compresses sharply, while the brown spread ticks up modestly in a short-lived risk reassessment and soon reverts. The result is a temporary divergence in relative financing costs rather than a persistent advantage for either sector. During the initial phase of credit expansion, the temporary widening of the brown spread induces a short-lived tilt toward brown lending. Brown loan volumes edge up and stay slightly positive, whereas green lending drops sharply on impact, then overshoots into positive territory before converging. Net worth in both sectors falls on impact and then rebounds; green firms gradually close the gap over the medium run. Green leverage declines markedly after the shock—consistent with cheaper funding and stronger internal cash generation—while brown leverage spikes and then drifts down, remaining above baseline for a time. As leverage rises, risk and adjustment costs depress profitability, and capital returns settle with brown marginally above green in the middle of the horizon.

In the steady state, because reserve-requirement cuts are broad-based, they do not create a persistent relative-cost wedge between green and brown credit. Consequently, relative loan rates and credit shares revert toward their pre-shock values and emissions return close to baseline; the instrument primarily reshapes the transition path—creating a temporary wedge and higher short-run volatility—rather than the long-run allocation. Overall, the reserve requirement shock releases liquidity and produces an asymmetric short-run response: brown borrowing and leverage expand more aggressively, while green balance sheets improve (lower leverage) after an initial dip in lending. Any near-term competitiveness gains for brown firms fade as leverage normalizes and capital returns converge, leaving no durable reallocation toward either sector.

4.3. Impacts of refinancing policy shocks

Fig. 3 presents the impulse response analysis of a 1% decrease in the green credit policy rate, illustrating its impact on carbon emissions, credit spreads, loan volumes, firms' net assets, and leverage ratios. The transmission mechanism unfolds as follows as set out in Fig. 3. The 1% cut in the green refinancing rate immediately compresses the external-finance premium for green firms, making funding cheaper and more accessible. Green loan originations jump on impact, briefly undershoot as adjustment costs bite, and then settle slightly above baseline. Carbon emissions show a short-lived positive blip (a scale effect as output expands) followed by a persistent decline as credit and production reallocate toward cleaner technologies. By contrast, the brown spread edges up modestly and quickly reverts, and brown borrowing and production remain largely unchanged, indicating that the targeted wedge leaves brown financing conditions essentially intact. Consequently, loan volumes for green firms jump on impact, briefly undershoot as adjustment costs bind, and then settle slightly above baseline. By contrast, brown loan volumes remain largely unchanged, showing only a mild, temporary uptick. This asymmetric response reallocates credit toward cleaner investment and supports the subsequent decline in emissions. Green leverage initially rises following the refinancing shock as firms expand borrowing faster than equity, but it gradually declines and reconverges as cheaper funding and stronger internal cash generation improve balance sheet strength; green net worth falls on impact due to valuation and cash-flow timing effects during rapid scaling and then recovers. Brown leverage shows only a small, short-lived increase, and brown net worth exhibits a mild dip followed by a temporary rise before returning to baseline.

In the steady state, if the refinancing wedge is maintained, the lower user cost of green capital delivers a durably greener steady state—a higher green share of credit and output and lower emissions—while avoiding the volatility associated with broad liquidity tools. For a one-off shock, most variables reconverge, but the transition still features an immediate emissions improvement after the short-run spike and a temporary compression of the green financing premium. In summary, targeted refinancing shifts financing

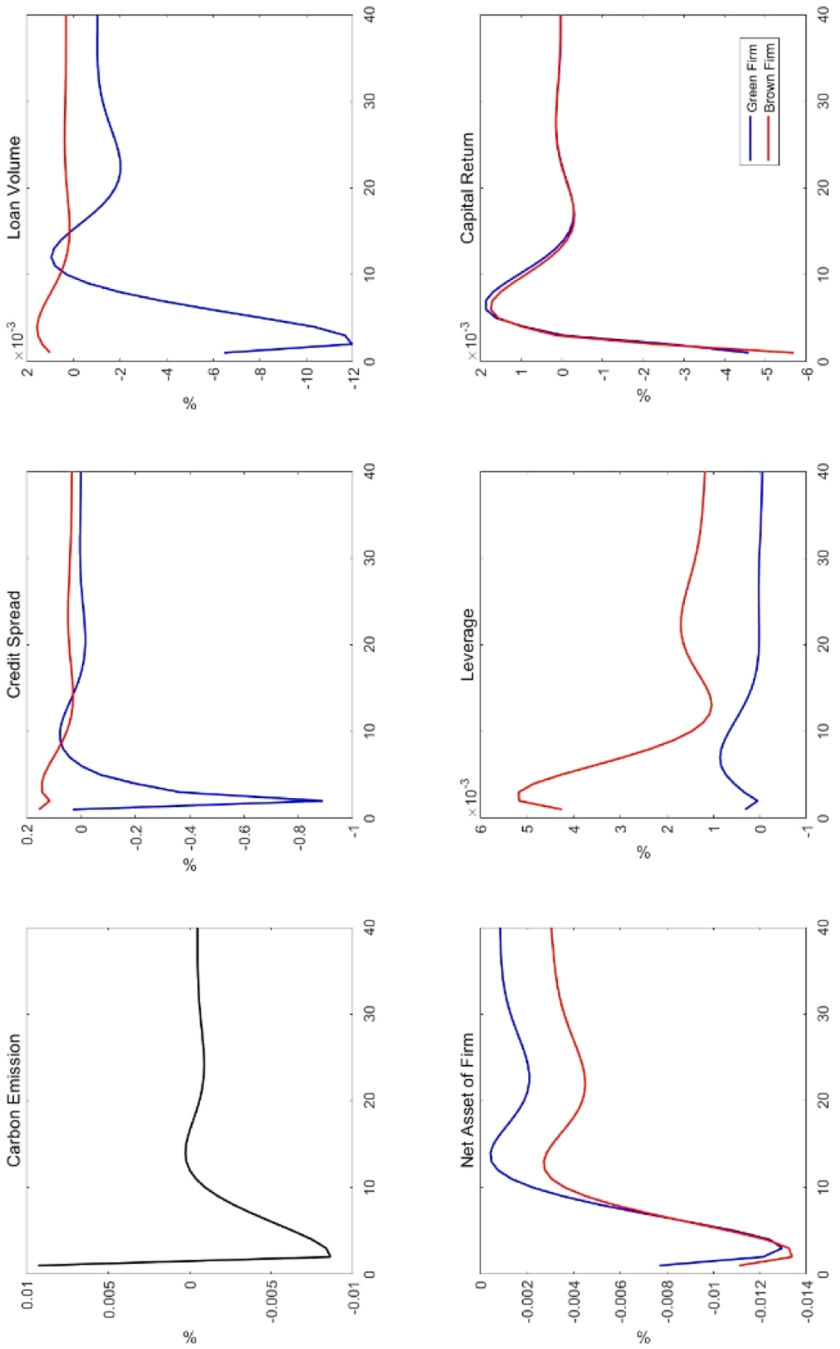


Fig. 2. Reserve Requirement Ratio Shock.

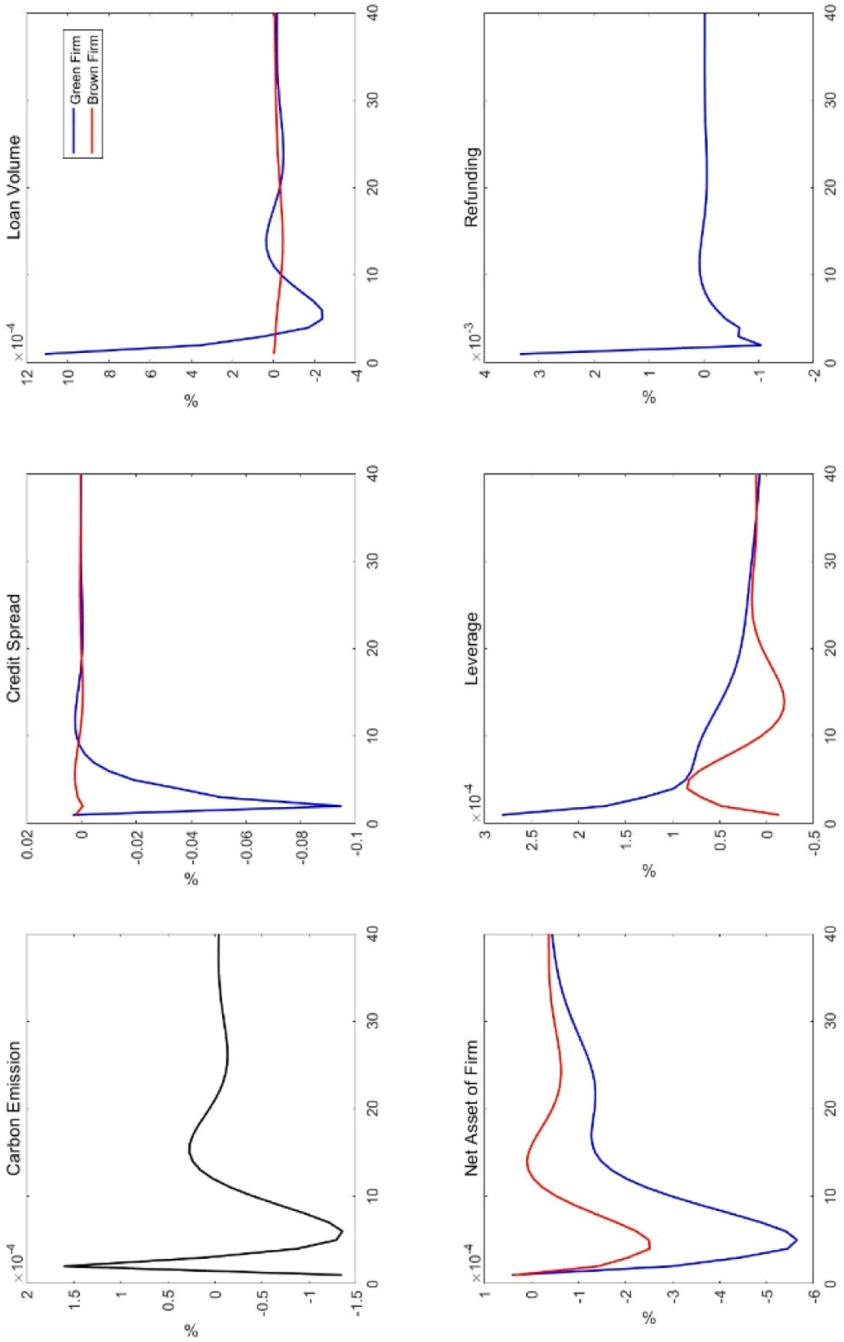


Fig. 3. Refinancing Policy Shock.

conditions decisively in favor of green projects: green spreads compress, green credit expands, leverage improves, and emissions decline after the brief scale-effect bump. Brown conditions remain largely unchanged, ensuring that the dynamic reallocation is driven by the targeted wedge rather than by broad liquidity.

4.4. Impacts of government loan guarantees

Fig. 4 presents the impulse response analysis of a one-unit increase in support under a soft budget constraint policy, illustrating its effects on carbon emissions, loan volumes, technological levels, net assets, and leverage ratios. The transmission mechanism unfolds as set out in Fig. 4.

First, the government guarantee compresses the external-finance premium for green firms, easing financing constraints and triggering a sharp jump in green loan originations on impact that later decline toward a small positive level. Brown loan volumes also rise modestly for a short period, rather than remaining unchanged. Green firms' technology initially improves strongly and then overshoots and briefly turns negative before recovering, indicating a more oscillatory adjustment than under refinancing. Consistent with these quantity and technology dynamics, carbon emissions dip on impact but then exhibit a positive hump and settle slightly above baseline, as scale effects from higher aggregate output partly offset compositional gains from greener production. Green firms experience a considerable increase in their net assets as a result of sustained growth under the policy support, while brown firms also see some increase, though to a lesser extent. This disparity highlights the favorable resource allocation that green firms enjoy through government backing. Additionally, the reduced financing costs under the soft budget constraint contribute to a more robust asset-liability structure for green firms, leading to a more stable capital base.

As for leverage ratios, both green and brown firms show a decrease in leverage, suggesting that green firms, in particular, are less reliant on debt financing due to the influx of new capital, thus reducing their financial risks. This decrease is especially notable for green firms, as they accumulate capital more quickly under the policy support. For the one-off loan guarantee plotted here, the relative-cost wedge is temporary, so most variables reconverge and emissions settle slightly above baseline as scale effects dominate. If, instead, the guarantee were maintained, the permanently lower green risk premium would shift the allocation toward a greener steady state with lower emissions; the transition would still be more oscillatory than under targeted refinancing.

In summary, the soft budget constraint compresses green borrowers' risk premia and raises pledgeable net worth, directly supporting green firms' expansion and innovation. Compared with targeted refinancing, the adjustment is larger but more oscillatory. For the one-off shock considered here, emissions dip on impact but then exhibit a positive hump and settle slightly above baseline. Under a persistent guarantee, by contrast, the economy would reallocate durably toward green activity and deliver lower long-run emissions. Brown firms receive only modest, short-lived spillovers in lending and leverage, so the competitive tilt primarily favors the green sector.

4.5. Comparative analysis of policy shocks

Fig. 5 provides a comparative analysis of the effects of three policy shocks on nine key indicators: carbon emissions, inflation, consumption, investment, credit spread, marginal cost, loan volume, risk-free interest rate, and M1 money supply. This analysis underscores the distinctive transmission mechanisms and impacts of each policy, particularly regarding economic stability and climate goals. The key impacts are set out in Fig. 5 and can be described as follows:

Carbon emissions. For the one-off shocks shown in Fig. 5, a reduction in reserve requirements produces an initial spike in carbon emissions, followed by a positive hump and slow convergence near, or slightly above, baseline. Refinancing delivers a modest but persistent decline in emissions. The soft budget constraint exhibits a small positive net effect: emissions dip briefly on impact, but subsequently rise and settle slightly above baseline as scale effects offset compositional gains.

Inflation. A reduction in reserve requirements generates the largest hump and the greatest volatility, consistent with broad credit expansion. Refinancing shows the smallest and most stable inflation response, reflecting its targeted nature. The impact of the loan guarantee is intermediate, with a mild initial decrease followed by a modest subsequent increase.

Consumption. Under the one-off shocks in Fig. 5, a reduction in reserve requirements generates a large positive hump in consumption, followed by a dip below baseline before convergence. This pattern is consistent with broad credit easing and subsequent payback. Refinancing produces a small initial decline and then a near-flat path close to zero, implying minimal demand volatility. The loan guarantee produces a modest, more persistent decline with limited oscillation. Overall, refinancing policy delivers the lowest consumption volatility, supporting macro-stability relative to a broad-based reduction in reserve requirements.

Investment. A reduction in reserve requirements produces a sharp drop on impact and then an overshooting rebound before normalizing, indicating a more unstable investment cycle. Refinancing policy results in a small initial increase followed by mild normalization toward baseline, consistent with targeted support rather than broad expansion. Loan guarantees show a hump-shaped rise that gradually fades. Taken together, the lower investment volatility under refinancing points to a more controlled and efficient allocation of resources toward sustainable projects than under a reduction in reserve requirements or loan guarantees.

Credit spread. With a reduction in reserve requirements, the spread compresses sharply on impact and then partly rebounds toward zero. Refinancing delivers a small decline followed by stability, while loan guarantees produce only a minor and temporary adjustment, with a slight uptick that quickly fades. This pattern indicates that targeted refinancing keeps credit costs most stable by channeling support precisely to green lending.

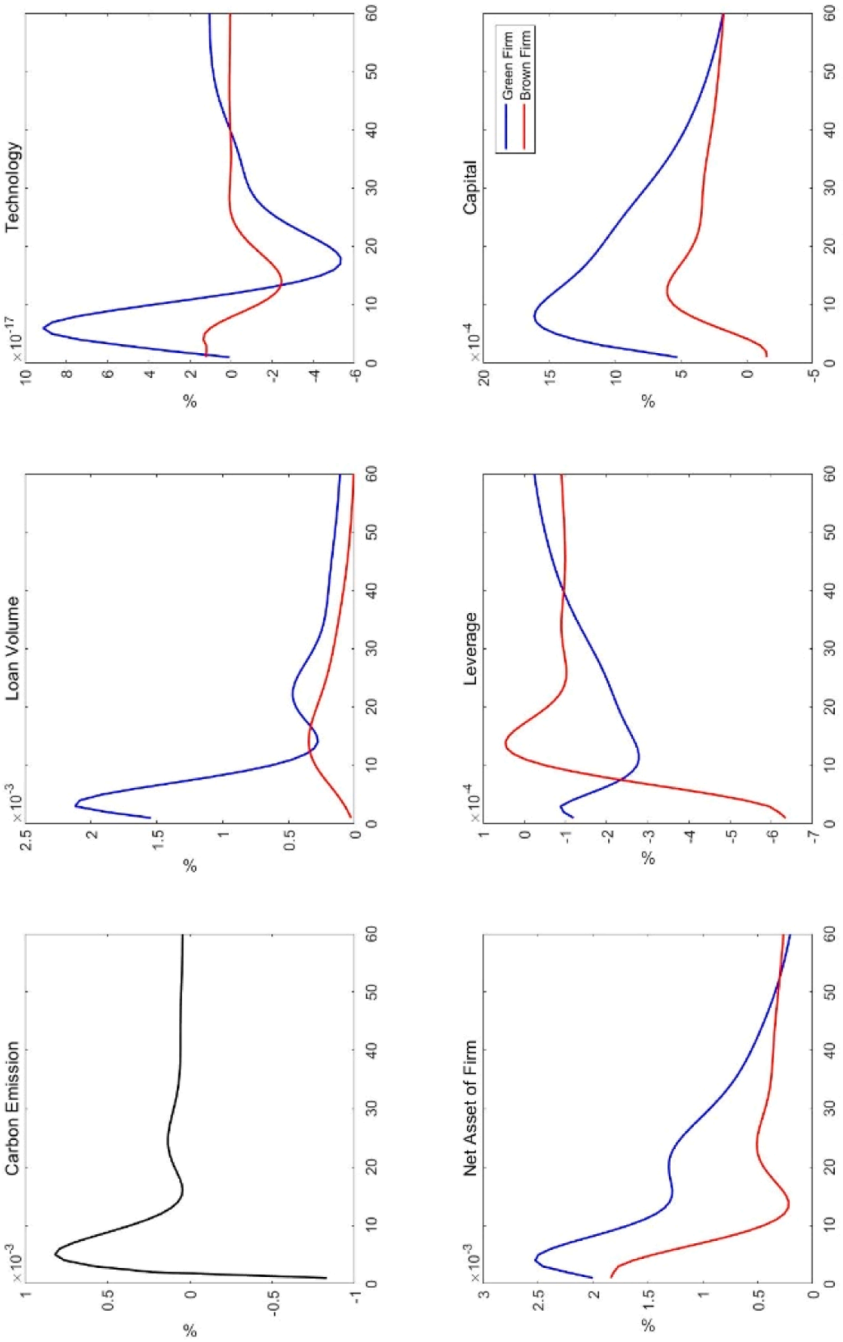


Fig. 4. Loan Guarantee Shock.

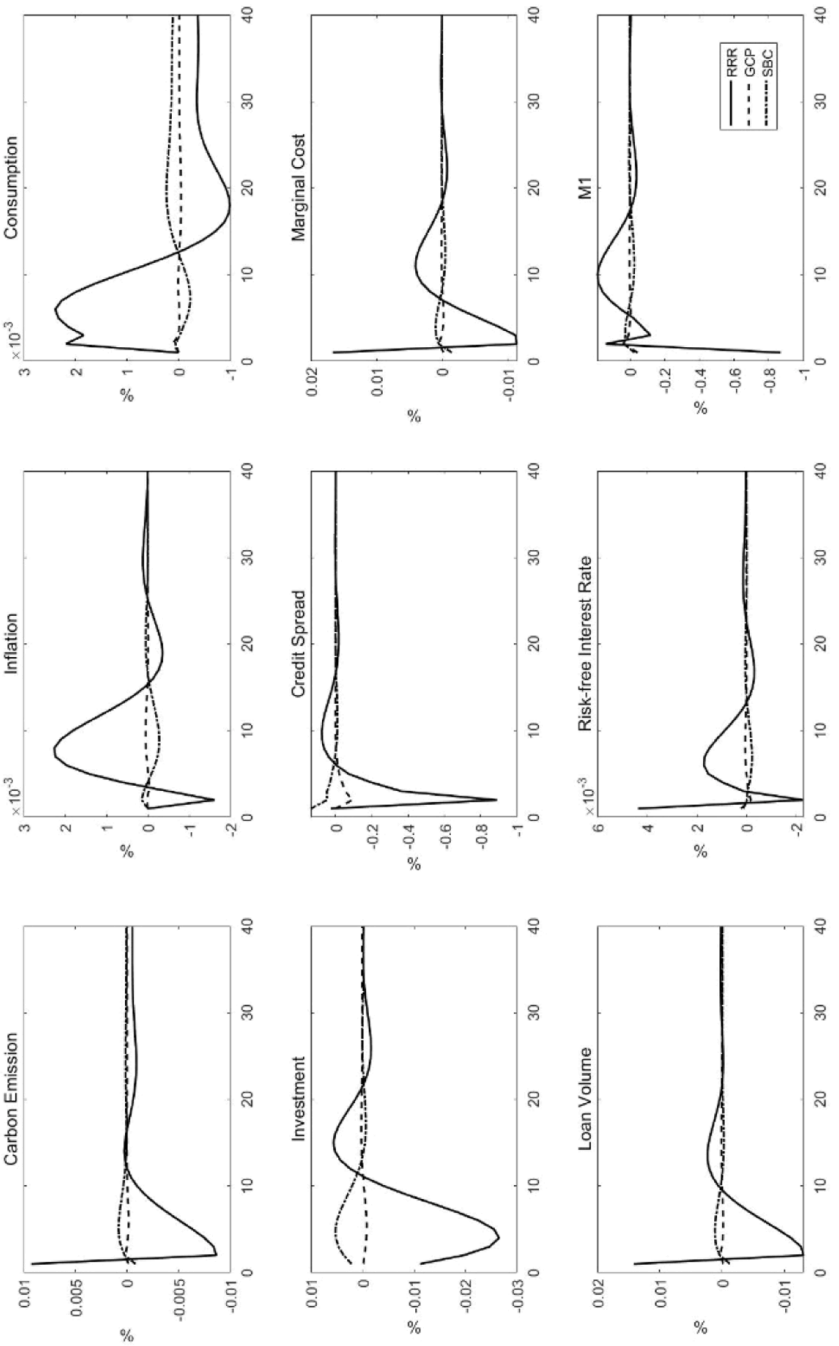


Fig. 5. Comparison of Three Policies.

Marginal cost. A reduction in reserve requirements generates the most visible hump-shaped increase in marginal cost, consistent with demand-driven pressures from broad liquidity. Bank refinancing and loan guarantees display modest, short-lived movements around zero.

Loan volume. A reduction in reserve requirements produces a large positive spike in total lending, followed by a swing below baseline before normalizing. This provides evidence of an unstable credit cycle under broad easing. Refinancing and loan guarantees yield more controlled increases, with refinancing showing the smallest amplitude. This is consistent with efficient, targeted allocation that avoids excessive debt build-up.

Risk-free interest rate. A reduction in reserve requirements generates the most pronounced movement in the risk-free interest rate, reflecting the broader liquidity expansion and the associated adjustment in household saving, consumption, and money demand. By contrast, targeted refinancing produces only a limited response because it affects the funding cost of green lending rather than aggregate liquidity conditions. Loan guarantees also have a relatively modest effect on the risk-free rate, as their main transmission channel operates through green-firm default risk and the external-finance premium rather than through the aggregate risk-free return.

M1 money supply. A reduction in reserve requirements produces the largest response in M1 money supply, consistent with the direct liquidity effect of relaxing reserve constraints. The increase in money supply supports the broad expansion of credit and activity but also contributes to greater short-run volatility. Refinancing and loan guarantees generate smaller movements in M1 because they are more targeted instruments. Refinancing mainly reallocates credit toward green firms, while loan guarantees operate through expected default losses and risk premia rather than through broad money creation.

Overall, a broad-based monetary policy easing through a reduction in reserve requirements can spur activity quickly, but at the cost of higher volatility and an emissions path that dips on impact, overshoots positively, and converges near or slightly above baseline, with no durable reallocation toward green production. The short-run competitiveness of brown firms reflects a temporary leverage build-up that later unwinds. By contrast, targeted bank refinancing reduces emissions modestly and persistently while keeping macroeconomic responses small and stable; loan growth is contained and more efficiently allocated to green projects. Loan guarantees also compress green risk premia and boost green lending and technology, but the transition is more oscillatory. For a one-off loan guarantee, emissions dip briefly, then rise and settle slightly above baseline as scale effects offset compositional gains. If the loan guarantee is maintained, however, it induces a greener steady state, albeit with a choppier adjustment path than targeted refinancing.

While the impulse responses emphasize short-run dynamics, the three finance-based instruments also have different implications for longer-run relative incentives. For the one-off shocks shown in Fig. 5, most variables gradually reconverge toward their steady-state values. Broad-based reserve requirement policy mainly affects aggregate liquidity and therefore generates larger transitional volatility, but it does not create a persistent relative-cost wedge between green and brown production. By contrast, targeted refinancing and loan guarantees reduce the financing cost or risk premium of green firms and therefore have stronger potential to support green reallocation when the policy wedge is maintained. It is therefore useful to distinguish between short-run dynamic responses and long-run incentive effects: the former capture transitional adjustment and volatility, while the latter indicate whether a policy can durably alter the relative competitiveness of green versus brown sectors. Table 2 summarizes the short-run transmission and the implied long-run incentive channel of the three finance-based instruments. Overall, the table shows that targeted refinancing provides the clearest climate-finance channel among the three finance-based instruments, whereas broad reserve requirements mainly operate as a macro-liquidity tool and loan guarantees generate stronger but more volatile adjustment dynamics.

4.6. Pigouvian carbon tax benchmark and steady-state carbon-pricing wedge

The preceding subsections focus on finance-based policy instruments. These policies affect emissions indirectly by changing credit conditions, lending spreads, leverage, and firms' external finance premia. This subsection introduces a Pigouvian carbon tax benchmark to compare these indirect financial channels with a standard direct carbon-pricing mechanism.

The Pigouvian tax rate is specified as proportional to aggregate emissions:

$$\tau_t^e = \varphi_{ce} CE_t$$

where $CE_t = CE_{g,t} + CE_{b,t}$. Carbon tax revenue is:

Table 2
Comparative overview.

Policy instrument	Short-run effect on emissions	Long-run incentive channel if the policy wedge is maintained	Overall implication
Reserve requirement (RRR)	Spike on impact → positive hump → converge near/slightly above baseline	No persistent shift in incentives; limited long-run emission reduction	Useful as macro stimulus but misaligned with climate goals
Green credit policy (GCP)	Modest, persistent decline; most stable path	If maintained: permanent reallocation toward green sector; lower emissions	Most effective and stable instrument for aligning finance with climate objectives
Soft budget constraint (SBC)	Brief dip, then small positive net; more oscillatory	If maintained: greener allocation; more oscillatory transition than GCP	Effective in reducing emissions, but less efficient than GCP

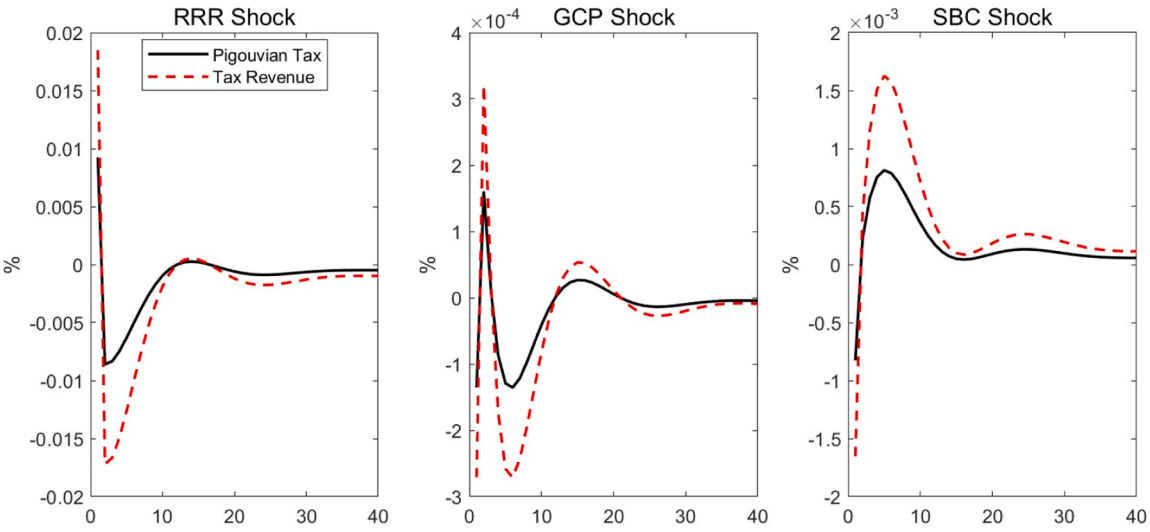


Fig. 6. Dynamic responses of the Pigouvian carbon tax and carbon tax revenue.

$$T_t^e = \tau_t^e CE_t$$

Since $\tau_t^e = \varphi_{ce} CE_t$, carbon tax revenue can be written as:

$$T_t^e = \varphi_{ce} CE_t^2$$

Thus, the tax rate moves one-for-one with aggregate emissions, while tax revenue responds more strongly because it depends on both the tax rate and the emissions base. The Pigouvian tax applies to emissions from both sectors, but the brown sector faces a larger effective unit cost because its emissions coefficient is higher.

Fig. 6 shows the dynamic responses of the Pigouvian carbon tax and the associated carbon tax revenue under the three policy shocks considered above. The solid line represents the Pigouvian carbon tax rate, while the dashed line represents carbon tax revenue. Under the RRR shock, the Pigouvian carbon tax and tax revenue display a sharp initial adjustment and then fall below the steady state before gradually converging back. This reflects the fact that the shock affects aggregate liquidity and production, causing emissions - and therefore the endogenous carbon tax - to move over the transition path. The stronger movement in tax revenue reflects the combined effect of changes in the tax rate and the emissions base.

Under the GCP shock, the responses are much smaller in magnitude. This suggests that targeted green refinancing mainly reallocates financial resources between sectors and stabilizes the emissions path, rather than generating a large aggregate-emissions response. In this case, the Pigouvian mechanism acts as a mild carbon-pricing adjustment around the transition path.

Under the SBC shock, both the Pigouvian carbon tax and tax revenue increase persistently before returning toward the steady-state levels. This indicates that government support for green lending can generate expansionary scale effects, raising aggregate production and emissions in the short run, even when the composition of activity shifts toward the green sector. The Pigouvian carbon tax responds endogenously to this emissions path.

Overall, Fig. 6 highlights the difference between the Pigouvian carbon tax benchmark and the finance-based policies. The Pigouvian carbon tax operates through a direct emissions-pricing channel, while the financial instruments operate indirectly through credit spreads, leverage, and external finance premia. The benchmark therefore clarifies how a standard carbon-pricing mechanism would respond to the same policy disturbances analysed in the baseline model.

Table 3 reports the steady-state carbon-pricing wedge implied by the Pigouvian carbon tax benchmark. Since aggregate emissions are positive in steady state, the Pigouvian carbon tax rate is also positive. Under the benchmark calibration, the steady-state Pigouvian carbon tax rate is 0.0060 and the associated carbon tax revenue is 0.0036. The brown-sector unit tax wedge is substantially larger than the green unit tax wedge, with a brown-to-green wedge ratio of approximately 5.27. This reflects the assumption that brown production is more emissions-intensive than green production. Therefore, even though both sectors are subject to the same carbon tax rate per unit of emissions, the effective production-cost penalty is much larger for the brown sector.

This steady-state wedge is conceptually different from the wedges generated by the finance-based instruments. Pigouvian carbon taxation directly prices emissions and changes sectoral production costs, whereas reserve requirements, targeted refinancing, and loan guarantees affect emissions indirectly through banks' balance sheets, credit spreads, leverage, and external finance premia.

Table 3
Steady-state carbon-pricing wedge under the Pigouvian benchmark.

Variable	Steady-state value
Aggregate emissions	0.60171
Green emissions	0.07482
Brown emissions	0.52689
Pigouvian tax rate	0.00602
Carbon tax revenue	0.00362
Green unit tax wedge	0.00060
Brown unit tax wedge	0.00317
Brown-to-green tax wedge ratio	5.2689
Tax revenue / output	0.00208

5. Conclusions

We develop and calibrate a Bernanke et al. (1999)-type DSGE model with financial frictions and two sectors, green and brown, to study how monetary, financial, and fiscal instruments can steer credit toward climate-related objectives. The three finance-based instruments analysed in the paper are: a broad reserve requirement policy, bank refinancing targeted at supporting green lending, and fiscal support through government guarantees for green loans. We further introduce a Pigouvian carbon-tax benchmark to compare these indirect financial-policy channels with a standard direct carbon-pricing mechanism.

The results highlight clear differences in transmission and policy trade-offs. A reduction in reserve requirements loosens liquidity economy-wide and stimulates activity, but it raises macroeconomic volatility and does not create a persistent relative incentive between green and brown firms. As a result, credit allocation and emissions gradually converge towards their baseline levels. By contrast, targeted bank refinancing compresses the external-finance premium for green borrowers, reallocates credit toward cleaner production, and delivers modest but persistent emission reductions with relatively small macroeconomic fluctuations. If the refinancing wedge is maintained, it induces a greener steady state with lower emissions. Government loan guarantees also reduce green firms' risk premia and support green lending and technology accumulation, but the transition is more oscillatory. For a one-off guarantee shock, emissions fall briefly and then settle slightly above baseline as scale effects partly offset the compositional shift toward green activity. If the guarantee is maintained, however, it can shift the steady state toward greener activity, although with a less stable adjustment path than targeted refinancing.

The Pigouvian carbon tax benchmark clarifies how these finance-based instruments differ from standard environmental taxation. The Pigouvian carbon tax operates directly through the production-cost margin by pricing emissions according to sectoral emission intensities. Since the brown sector is more emissions-intensive than the green sector, the effective unit tax wedge is substantially larger for brown production. In contrast, the finance-based instruments operate indirectly through bank balance sheets, funding costs, credit spreads, leverage, and external finance premia. The benchmark therefore shows that carbon taxation and green financial policies are not equivalent: Pigouvian carbon taxation raises the cost of emissions-intensive production, whereas green refinancing and loan guarantees lower the financing cost of cleaner activity. Both channels can shift relative incentives, but they do so through different margins and with different implications for transitional volatility and long-run allocation.

Overall, targeted green refinancing emerges as the most stable finance-based instrument in the model. It supports green credit allocation, reduces emissions more persistently than broad liquidity policy, and generates lower macroeconomic volatility than loan guarantees. Broad reserve requirement policy is effective as a macro-liquidity tool but is poorly targeted for climate objectives. Loan guarantees can strongly support green expansion, but their effects are more volatile and may generate short-run scale effects that offset some environmental gains. The Pigouvian carbon tax benchmark provides a useful long-run reference point: direct carbon pricing creates a transparent sectoral cost wedge, while green financial policies work through credit-market frictions. A promising direction for future research is to study the joint design of Pigouvian carbon taxation and green financial policies, allowing carbon pricing and targeted credit support to complement one another in achieving climate and financial stability objectives.

CRediT authorship contribution statement

Yener Altunbas: Writing – review & editing, Methodology, Conceptualization. **Maria Mazzuca:** Writing – review & editing, Conceptualization. **Xiaoxi Qu:** Writing – review & editing, Methodology, Conceptualization. **John Thornton:** Writing – review & editing, Conceptualization.

Appendix

Labor supply equation:

$$\xi L_t^{\sigma_l} = \frac{W_t}{P_t} C_t^{-\sigma_c} \tag{A.1}$$

Euler equation of consumption decision:

$$\frac{1}{r_t} = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \tag{A.2}$$

Money demand equation:

$$\left(\frac{M_t}{P_t}\right)^{\sigma_m} = \zeta\left(\frac{r_t}{r_t - 1}\right) C_t^{\sigma_c} \tag{A.3}$$

Marginal utility of consumption:

$$\lambda_t = C_t^{-\sigma_c} \tag{A.4}$$

Price of the final commodity:

$$1 = \theta_p(\pi_t)^{(\epsilon_p - 1)} + (1 - \theta_p)\left(\frac{P_t^*}{P_t}\right)^{(1-\epsilon_p)} \tag{A.5}$$

Output of green products:

$$Y_{g,t} = (\varphi)\left(\frac{P_{g,t}}{P_t}\right)^{-\chi} Y_t \tag{A.6}$$

Output of brown products:

$$Y_{b,t} = (1 - \varphi)\left(\frac{P_{b,t}}{P_t}\right)^{-\chi} Y_t \tag{A.7}$$

Aggregation price:

$$P_t = \left[\varphi\left(P_{g,t}\right)^{1-\chi} + (1 - \varphi)\left(P_{b,t}\right)^{1-\chi}\right]^{\frac{1}{1-\chi}} \tag{A.8}$$

Total marginal cost:

$$mc_t = MC_t^n / P_t \tag{A.9}$$

NKPC:

$$\frac{P_t^*}{P_t} = \frac{\epsilon_p}{\epsilon_p - 1}\frac{f_t^1}{f_t^2} \tag{A.10}$$

$$f_t^1 = \lambda_t mc_t Y_t + \beta\theta_p E_t \pi_{t+1}^{\epsilon_p} f_{t+1}^1 \tag{A.11}$$

$$f_t^2 = \lambda_t Y_t + \beta\theta_p E_t \pi_{t+1}^{\epsilon_p - 1} f_{t+1}^2 \tag{A.12}$$

Price discrete kernel:

$$d_t^p = (1 - \theta_p)\left(\pi_t^*\right)^{-\epsilon_p} + \theta_p \pi_t^{\epsilon_p} d_{t-1}^p \tag{A.13}$$

$$Y_t = d_t^p Y_t^f \tag{A.14}$$

Production function of green firms:

$$Y_{g,t}^j = A_{g,t}\left(K_{g,t}^j\right)^{\alpha_g}\left(L_{g,t}^j\right)^{1-\alpha_g} \tag{A.15}$$

Production function of brown firms:

$$Y_{b,t}^j = A_{b,t}\left(K_{b,t}^j\right)^{\alpha_b}\left(L_{b,t}^j\right)^{1-\alpha_b} \tag{A.16}$$

Under symmetric equilibrium, firm-level variables aggregate to $Y_{i,t}$, $K_{i,t}$, and $L_{i,t}$
Labor demand equation of green firms:

$$L_{g,t} = (1 - \alpha_g) mc_{g,t} \frac{Y_{g,t}}{W_{g,t}} \tag{A.17}$$

Labor demand equation of brown firms:

$$L_{b,t} = (1 - \alpha_b) mc_{b,t} \frac{Y_{b,t}}{W_{b,t}} \tag{A.18}$$

Marginal cost of green firms:

$$mc_{g,t} = MC^{n}_{g,t}/P_t \tag{A.19}$$

Marginal cost of brown firms:

$$mc_{b,t} = MC^{n}_{b,t}/P_t \tag{A.20}$$

Capital return rate of green firms:

$$E_t\left\{R^{k}_{g,t+1}\right\} = E_t\left[\alpha_g mc_{g,t+1}\frac{Y_{g,t+1}}{K_{g,t}} + Q_{t+1}(1-\delta)\right]\Big/ Q_t \tag{A.21}$$

Capital return rate of brown firms:

$$E_t\left\{R^{k}_{b,t+1}\right\} = E_t\left[\alpha_b mc_{b,t+1}\frac{Y_{b,t+1}}{K_{b,t}} + Q_{t+1}(1-\delta)\right]\Big/ Q_t \tag{A.22}$$

Real interest rate:

$$r_t \equiv E_t\left(\frac{i_t}{\pi_{t+1}}\right) \tag{A.23}$$

Sum of capital of green and brown firms:

$$K_t = K_{g,t} + K_{b,t} \tag{A.24}$$

Sum of labour of green and brown firms:

$$L_t = L_{g,t} + L_{b,t} \tag{A.25}$$

Wage of green and brown firms:

$$W_t = W_{g,t} \tag{A.26}$$

$$W_t = W_{b,t} \tag{A.27}$$

Capital accumulation equation:

$$K_t = (1-\delta)K_{t-1} + \left[1 - \frac{\psi_1}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right] I_t \tag{A.28}$$

Tobin Q:

$$Q_t\left[1 - \frac{\psi_1}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 - \psi_1\left(\frac{I_t}{I_{t-1}} - 1\right)\frac{I_t}{I_{t-1}}\right] + \beta E_t \frac{\lambda_{t+1}}{\lambda_t}\psi_1\left(\frac{I_{t+1}}{I_t} - 1\right)\left(\frac{I_{t+1}}{I_t}\right)^2 Q_{t+1} = 1 \tag{A.29}$$

Balance sheet of green firms:

$$Q_t K_{g,t} = N_{g,t} + B_{g,t} \tag{A.30}$$

Balance sheet of brown firms:

$$Q_t K_{b,t} = N_{b,t} + B_{b,t} \tag{A.31}$$

Capital leverage of green firms:

$$LEV_{g,t} = Q_t K_{g,t}/N_{g,t} \tag{A.32}$$

Capital leverage of brown firms:

$$LEV_{b,t} = Q_t K_{b,t}/N_{b,t} \tag{A.33}$$

Green-firm loan-contract constraint:

$$\left[g_{t+1} + \Gamma(\overline{\omega}_{g,t+1}, \sigma_{\omega g}) - \tau G_{\omega g}\left(\overline{\omega}_{g,t+1}, \sigma_{\omega g}\right)\right] R^{k}_{g,t+1} Q_t K_{g,t} = i_{t+1}(Q_t K_{g,t} - N_{g,t}) \tag{A.34}$$

The degree of government guarantee:

$$g_{t+1} = \frac{G_{t+1}}{R^{k}_{g,t+1} Q_t K_{g,t}} \tag{A.35}$$

Brown-firm loan-contract constraint:

$$\left[\Gamma(\overline{\omega}_{b,t+1},\sigma_{\omega b})-\tau G_{\omega,b}\left(\overline{\omega}_{b,t+1},\sigma_{\omega b}\right)\right]R^{k}_{b,t+1}Q_tK_{b,t}=i_{t+1}(Q_tK_{b,t}-N_{b,t}) \tag{A.36}$$

Profit maximization of green firms:

$$\left[1-\Gamma\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)-g_{t+1}\right]\frac{R^{k}_{g,t+1}}{i_{t+1}}=\frac{1}{LEV_{g,t}}\eta_{g,t} \tag{A.37}$$

$$\eta_{g,t}=\frac{1-F\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)}{1-F\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)-\tau\overline{\omega}_{g,t+1}F_{\omega}\left(\overline{\omega}_{g,t+1},\sigma_{\omega g}\right)} \tag{A.38}$$

Profit maximization of brown firms:

$$\left[1-\Gamma\left(\overline{\omega}_{b,t+1},\sigma_{\omega b}\right)\right]\frac{R^{k}_{b,t+1}}{i_{t+1}}=\frac{1}{LEV_{b,t}}\eta_{b,t} \tag{A.39}$$

$$\eta_{b,t}=\frac{1-F\left(\overline{\omega}_{b,t+1},\sigma_{\omega b}\right)}{1-F\left(\overline{\omega}_{b,t+1},\sigma_{\omega b}\right)-\tau\overline{\omega}_{b,t+1}F_{\omega}\left(\overline{\omega}_{b,t+1},\sigma_{\omega b}\right)} \tag{A.40}$$

Financing premium of green firms:

$$G_{t+1}+\overline{\omega}_{g,t+1}R^{k}_{g,t+1}Q_tK_{g,t}=R^{l}_{g,t+1}B_{g,t} \tag{A.41}$$

Financing premium of brown firms:

$$\overline{\omega}_{b,t+1}R^{k}_{b,t+1}Q_tK_{b,t}=R^{l}_{b,t+1}B_{b,t} \tag{A.42}$$

Net assets accumulation of green firms:

$$N_{g,t}=\gamma_g\left[R^{k}_{g,t}Q_{t-1}K_{g,t-1}\left(1-\tau G_{\omega,g}\left(\overline{\omega}_{g,t},\sigma_{\omega g}\right)+g_t\right)-i_tB_{g,t-1}\right] \tag{A.43}$$

Net assets accumulation of brown firms:

$$N_{b,t}=\gamma_b\left[R^{k}_{b,t}Q_{t-1}K_{b,t-1}\left(1-\tau G_{\omega,b}\left(\overline{\omega}_{b,t},\sigma_{\omega b}\right)\right)-i_tB_{b,t-1}\right] \tag{A.44}$$

Profit maximization of banks that provide loans to green firms:

$$\begin{aligned}\frac{\partial\Pi_{Bg}}{\partial B_{g,t}}=&\left(1-o_g\right)R^{l}_{g,t}-i_t\frac{(1-\varpi_t)}{\left(1-R^{r}_{t}\right)}-R^{h}_{g,t}\varpi_t\\&-\left\{\begin{array}{c}\dfrac{\psi_2}{2}\left(\dfrac{B_{g,t}}{B_{g,t-1}}-1\right)^2+\psi_2\dfrac{B_{g,t}}{B_{g,t-1}}\left(\dfrac{B_{g,t}}{B_{g,t-1}}-1\right)+\dfrac{\psi_3}{2}\left(\dfrac{\frac{(1-\varpi_t)B_{g,t}}{\left(1-R^{r}_{t}\right)}}{\frac{(1-\varpi_{t-1})B_{g,t-1}}{\left(1-R^{r}_{t-1}\right)}}-1\right)^2\dfrac{(1-\varpi_t)}{\left(1-R^{r}_{t}\right)}\\+\psi_3\left(\dfrac{\frac{(1-\varpi_t)B_{g,t}}{\left(1-R^{r}_{t}\right)}}{\frac{(1-\varpi_{t-1})B_{g,t-1}}{\left(1-R^{r}_{t-1}\right)}}-1\right)\dfrac{(1-\varpi_t)}{\left(1-R^{r}_{t}\right)}\dfrac{\frac{(1-\varpi_t)B_{g,t}}{\left(1-R^{r}_{t}\right)}}{\frac{(1-\varpi_{t-1})B_{g,t-1}}{\left(1-R^{r}_{t-1}\right)}}+\dfrac{\psi_4}{2}\left(\dfrac{\varpi_tB_{g,t}}{\varpi_{t-1}B_{g,t-1}}-1\right)^2\varpi_t+\psi_4\left(\dfrac{\varpi_tB_{g,t}}{\varpi_{t-1}B_{g,t-1}}-1\right)\varpi_t\dfrac{\varpi_tB_{g,t}}{\varpi_{t-1}B_{g,t-1}}\end{array}\right\}\\&+\beta E_t\left\{\begin{array}{c}\psi_2\left(\dfrac{B_{g,t+1}}{B_{g,t}}-1\right)\left(\dfrac{B_{g,t+1}}{B_{g,t}}\right)^2+\psi_3\dfrac{(1-\varpi_t)}{\left(1-R^{r}_{t}\right)}\left(\dfrac{\frac{(1-\varpi_{t+1})B_{g,t+1}}{\left(1-R^{r}_{t+1}\right)}}{\frac{(1-\varpi_t)B_{g,t}}{\left(1-R^{r}_{t}\right)}}-1\right)\left(\dfrac{\frac{(1-\varpi_{t+1})B_{g,t+1}}{\left(1-R^{r}_{t+1}\right)}}{\frac{(1-\varpi_t)B_{g,t}}{\left(1-R^{r}_{t}\right)}}\right)^2\\+\psi_4\varpi_t\left(\dfrac{\varpi_{t+1}B_{g,t+1}}{\varpi_tB_{g,t}}-1\right)\left(\dfrac{\varpi_{t+1}B_{g,t+1}}{\varpi_tB_{g,t}}\right)^2\end{array}\right\}=0\end{aligned} \tag{A.45}$$

Profit maximization of banks that provide loans to brown firms:

$$\frac{\partial \Pi_{Bb}}{\partial B_{b,t}} = (1-o_b)R^l_{b,t} - \frac{i_t}{(1-R^r_t)} - \left\{ \begin{array}{c} \frac{\psi_5}{2}\left(\frac{B_{b,t}}{B_{b,t-1}}-1\right)^2 + \frac{\psi_6}{2}\frac{1}{(1-R^r_t)}\left(\frac{B_{b,t}}{B_{b,t-1}}-1\right)^2 + \\ \psi_5\left(\frac{B_{b,t}}{B_{b,t-1}}-1\right)\frac{B_{b,t}}{B_{b,t-1}} + \psi_6\left(\frac{\frac{B_{b,t}}{(1-R^r_t)}}{\frac{B_{b,t-1}}{(1-R^r_{t-1})}}-1\right)\frac{\frac{B_{b,t}}{(1-R^r_t)}}{\frac{B_{b,t-1}}{(1-R^r_{t-1})}}\frac{1}{(1-R^r_t)} \end{array} \right\} + \beta E_t \left\{ \psi_5\left(\frac{B_{b,t+1}}{B_{b,t}} - 1\right)\left(\frac{B_{b,t+1}}{B_{b,t}}\right)^2 + \psi_6\frac{1}{(1-R^r_t)}\left(\frac{\frac{B_{b,t+1}}{(1-R^r_{t+1})}}{\frac{B_{b,t}}{(1-R^r_t)}}-1\right)\left(\frac{\frac{B_{b,t+1}}{(1-R^r_{t+1})}}{\frac{B_{b,t}}{(1-R^r_t)}}\right)^2 \right\} = 0 \tag{A.46}$$

Demand for deposits:

$$D_t = \frac{B_{b,t} + (1-\varpi_t)B_{g,t}}{1-R^r_t} \tag{A.47}$$

$$B_{b,t} = \left(1-R^r_t\right)D_{b,t} \tag{A.48}$$

$$D_t = D_{g,t} + D_{b,t} \tag{A.49}$$

$$B_{g,t} = \left(1-R^r_t\right)D_{g,t} + H_{g,t} \tag{A.50}$$

Government budget constraint:

$$Gov_t + G_{t+1} = \frac{M_t - M_{t-1}}{P_t} + T_t + T^e_t \tag{A.51}$$

$$T^e_t = \tau^e_t CE_{b,t} \tag{A.52}$$

$$Gov_t = \psi_7 Y^f_t \tag{A.53}$$

Market clearing:

$$Y^f_t = C_t + Gov_t + G_{t+1} + I_t + \tau G_\omega\left(\overline{\omega}_{g,t+1}, \sigma_{\omega g}\right)R^k_{g,t+1}Q_t K_{g,t} + \tau G_\omega\left(\overline{\omega}_{b,t+1}, \sigma_{\omega b}\right)R^k_{b,t+1}Q_t K_{b,t} \tag{A.54}$$

Carbon emission

$$CE_{g,t} = \frac{\theta_{ge}}{A_{g,t}}Y_{g,t} \tag{A.55}$$

$$CE_{b,t} = \frac{\theta_{be}}{A_{b,t}}Y_{b,t} \tag{A.56}$$

$$mc^\tau_{b,t} = mc_{b,t} + \tau^e_t\frac{\theta_{be}}{A_{b,t}} \tag{A.57}$$

$$CE_t = CE_{g,t} + CE_{b,t} \tag{A.58}$$

$$T^e_{g,t} = \tau^e_t\frac{\theta_{ge}}{A_{g,t}}Y_{g,t}, T^e_{b,t} = \tau^e_t\frac{\theta_{be}}{A_{b,t}}Y_{b,t} \tag{A.59}$$

$$mc^\tau_{g,t} = mc_{g,t} + \tau^e_t\frac{\theta_{ge}}{A_{g,t}}, mc^\tau_{b,t} = mc_{b,t} + \tau^e_t\frac{\theta_{be}}{A_{b,t}} \tag{A.60}$$

In the baseline financial-policy experiments, $\tau^e_t = 0$, so $mc^\tau_{g,t} = mc_{g,t}$and $mc^\tau_{b,t} = mc_{b,t}$. In the Pigouvian-tax benchmark, $mc_{g,t}$and $mc_{b,t}$in the sectoral optimality conditions are replaced by $mc^\tau_{g,t}$and $mc^\tau_{b,t}$, respectively.

Shock of reserve requirement ratio:

$$\log R^r_t - \log R^r_{ss} = \rho_r\left(\log R^r_{t-1} - \log R^r_{ss}\right) + (1-\rho_r)\left[\begin{array}{c}\phi_Y(\log Y_t - \log Y_{ss}) \\ +\phi_\pi(\log\pi_t - \log\pi_{ss})\end{array}\right] + \varepsilon^{R^r}_t \tag{A.61}$$

Shock of refinancing rate for green firms:

$$\log R^h_{g,t} - \log R^h_{g,ss} = \rho_h\left(\log R^h_{g,t-1} - \log R^h_{g,ss}\right) + (1-\rho_h)\left[(\log i_t - \log i_{ss}) - \quad \mu_1\left[\left(\log B_{g,t} - \log B_{g,ss}\right) - \left(\log B_{g,t-1} - \log B_{g,ss}\right)\right]\right] + \varepsilon^{R^h_g}_t \tag{A.62}$$

Shock of refinancing pledge rate of green firms:

$$\log \varpi_t - \log \varpi_{ss} = \rho_{\varpi}(\log \varpi_{t-1} - \log \varpi_{ss}) + (1-\rho_{\varpi})\mu_2\left[\left(\log B_{g,t} - \log B_{g,ss}\right) - \left(\log B_{g,t-1} - \log B_{g,ss}\right)\right] + \varepsilon^{\varpi}_t \tag{A.63}$$

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