Can Sustainability-Linked Lending Reconcile Environmental and Financial Motives?

Ammu George[1], Jingong Huang[2], He Nie[3,*], and Taojun Xie[1]

[1]Asia Competitiveness Institute, Lee Kuan Yew School of Public Policy, National University of Singapore

[2]University of Nottingham Ningbo China

[3]Economics and Management School, Wuhan University, China

[*]Corresponding author: henieecon@gmail.com

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Abstract

Differentiated lending terms for clean and dirty capital have become a popular tool among commercial banks as they promote themselves as advocates of environmental sustainability. Using a two-sector New Keynesian Dynamic Stochastic General Equilibrium (DSGE) model where emissions are a by-product of dirty capital, we propose a framework of emission-elastic lending rates where banks lower lending rates to clean capital investment agencies when emission growth exceeds the target. This paper finds that differential lending rates aid environmental policymakers in their emission reduction goal while also being compatible with banks' profit maximisation. However, the accompanying financial sector uncertainty may limit the social welfare improvement that emission-elastic lending rates could bring about.

Keywords: Climate policy, Monetary policy, New Keynesian model, Bank lending, Macroprudential policy, Green finance

JEL Classifications: E32, E44, E52, E58, G21

1 Introduction

"While carbon pricing is among the most effective policy tools to direct spending and investment out of dirty energy and into green alternatives, many countries are reluctant to use this policy lever. They fear a loss of international competitiveness, especially in high-emission sectors such as steel or chemicals."

—Jeff Kearns (May 19, 2022)[1]

"As bank lending interest rates and the lending-deposit interest spreads capture the efficiency with which banks allocate societys savings to its most productive uses, high lending rates and spreads pose a challenge for policy makers..."

—Erik Feyen & Igor Zuccardi (November 02, 2020)[2]

In recent years, many commercial banks across the globe have announced their intention to reduce "financed emissions". This is evident from the increase in the Net-Zero Banking Alliance (NZBA) membership, which requires banks to allocate more of their financing to activities that lower carbon emissions, from 43 to 123 banks in 2022 (Mckinsey, 2022b). To fulfil their commitment to NZBA, several banks have recently started to offer sustainability-linked loans with reduced loan interest rates to corporates whose activities align with emission reduction (Mckinsey, 2022a; Euromoney, 2022; OCBC, 2023; ABNAMRO, 2023). Since preferential loan rates are offered for clean production, corporates are expected to use this cheaper financing option to purchase more clean capital. With cheaper clean capital inputs, firms substitute towards clean modes of production. This abets the environmental policymakers towards their goal of emission reduction.

This article argues that the outcome of such preferential lending rates to clean corporates, which we term ***emission-elastic lending rates***, extends beyond emission abatement. We find that such favourable lending rates spur the loan demand from corporates to purchase clean capital inputs, leading to an expansion in aggregate loans and a consequent increase in bank profit margin. Thus, emission-elastic lending rates complement

[1] Available at the International Monetary Fund (IMF) Blog.
[2] Available at the World Bank Blog.

the banks' larger financial motivation towards profit maximisation. We also find that this sudden lending expansion creates financial sector uncertainty concerns, adversely affecting households' utility. Consequently, the presence of emission-elastic lending rates does *not* essentially translate to an adequate social welfare improvement. We capture the findings by extending the banking sector framework following Benes & Kumhof (2015) in a New Keynesian Dynamic Stochastic General Equilibrium (DSGE) model where emissions emerge as a by-product of using dirty capital inputs in production (Annicchiarico & Di Dio, 2015).

Banks play a central role in financing. As an important intermediary of loanable funds, we identify three critical implications of banks' prerogative in offering emission-elastic lending rates to corporates that engage in clean capital purchases. First, the lower financing cost makes clean capital inputs cheaper and helps the firms to offset the emission abatement costs. Consequently, firms are incentivised to substitute dirty capital with clean capital as inputs in production, resulting in emission reduction.

Second, favourable lending rates increase corporate loan demand to finance their clean capital purchases. The rise in loan demand expands aggregate loan volume, which can help to more than offset the banks' lower interest income due to its differentiated lending rate initiative. Hence, emission-elastic lending rates can increase banks' profit margins.

Finally, the issuance of emission-elastic lending rates is a double-edged sword. Although such preferential lending terms result in emission reduction and help banks increase profit margins, the improvement in social welfare is not akin to the increase in bank profits. The expansion in lending following the issuance of emission-elastic lending rates raises agents' fears of financial sector uncertainty. The volatility in bank lending increases instability in aggregate deposits (financing through the money creation channel). Agents prefer stable deposit patterns as their lifetime expected utility depends on deposit money balances. Consequently, emission-elastic lending rates lead to only a marginal improvement in social welfare, largely owing to the associated drop in emissions.

To perform our analysis, we developed an E-DSGE model where capital investment funds (corporates) borrow from banks to finance capital purchases. We follow Benes & Kumhof (2015) to model the banking sector as an intermediary of loanable funds.

Specifically, banks create deposits (financing through money creation) to fund loans rather than banks borrowing from depositors and lending to borrowers. This ingredient makes the changes in credit associated with emission-elastic lending rates being funded by the changes in deposits. This directly impacts social welfare as deposits are part of the agents' lifetime utility function (agents prefer financial sector certainty through stable deposit balances). Our model comprises two types of capital investment funds that secure loans from banks - 1) clean, which purchases clean capital, and 2) dirty, which engages in the dirty capital purchase. Manufacturing firms rent both types of capital from the respective capital investment funds and use them as production inputs. Emissions are a by-product of dirty capital usage. When emission growth exceeds the target, banks provide preferential treatment to clean capital investment funds through emission-elastic lending rates.

In our simulations, the emission-elastic lending rate lowers the cost of clean capital compared to dirty capital when emission growth exceeds the target, causing firms to substitute dirty with clean capital inputs. In an otherwise identical environment, commercial banks can choose not to differentiate the lending rates between clean and dirty capital loans (*baseline* where emission-elastic lending rate coefficient is zero), opt for a competitive emission-elastic lending rate coefficient which maximises bank profit (*competitive* regime) or the social planner decides the emission-elastic lending rate coefficient which maximises social welfare (*socially optimal* regime).

Our paper makes three main contributions to the literature on commercial banks' role in greening the economy. First, we are the first to evaluate the economic and environmental implications of the recent initiative from commercial banks to offer preferential lending rates to corporates that engage in activities which reduce emissions. To our knowledge, no existing paper integrates the E-DSGE framework with a full-fledged banking sector. We develop a novel framework of emission-elastic lending rates, where the loan interest rate to clean capital investment funds is tied to emission growth[3]. When emission growth exceeds the target, the loan interest rate charged to clean capital investment funds lowers. This creates a wedge between clean and dirty capital loan interest rates, reducing

[3]A related paper George et al. (2022) ties interest rates to emission growth. In contrast, our study delineates clean and dirty capital lending rates using a framework where banks lower the loan interest rate charged to clean capital investment funds when emission growth exceeds the target.

the cost of clean capital compared to dirty capital.

Our second contribution is analysing the changes in bank profit and social welfare associated with the emission-elastic lending rates. We find that banks can significantly increase their profit margin while raising the emission-elastic lending rate coefficient. This is largely owing to the rise in aggregate loans, which more than offsets the loss in interest income. However, social welfare does not witness similar gains when the emission-elastic lending rate coefficient increases due to agents' concerns about financial sector uncertainty.

Finally, we document that although emission-elastic lending rates aid in a smoother green transition when the economy faces a permanent carbon tax shock, it exacerbates the financial sector uncertainty. Without emission-elastic lending rates, a permanent rise in carbon tax causes a steeper substitution from dirty capital to clean capital. With emission-elastic lending rates, the relative cost of clean capital compared to dirty capital adjusts since emission drops below target on account of the carbon tax shock. Consequently, the firms' reallocation from dirty to clean capital is more subdued, resulting in a gradual transition to a greener economy. However, we find that financial sector uncertainty, through lending and deposit volatility, increases when emission-elastic lending rate interacts with the carbon tax shock.

The remainder of the paper proceeds as follows. Section 2 reviews the literature. Section 3 presents the E-DSGE model with a banking sector that offers emission-elastic lending rates. Section 4 elaborates on the model parameterisation. Section 5 presents outcomes on social welfare and bank profit associated with emission-elastic lending rates. Section 6 shows the equilibrium dynamics. Section 7 discusses the role of clean capital productive efficiency and emission disutility in the implications of emission-elastic lending rates. Section 8 shows emission-elastic lending rates help in a gradual transition to a greener economy when a carbon tax is introduced. Finally, section 9 concludes.

2 Related Literature

This paper is related to several branches of literature. First, our study adds to the growing literature on E-DSGE models to study business cycles and the green policy (Annicchiarico & Di Dio, 2015; Annicchiarico et al., 2022; Barrage, 2020; Borenstein et al., 2019; Diluiso et al., 2020; Dissou & Karnizova, 2016; Fischer & Springborn, 2011; Heutel, 2012; George et al., 2022; Pan, 2019).[4] Angelopoulos et al. (2013) and Fischer & Heutel (2013) are early contributions to the literature on environmental policy and business cycles. They use the real business cycle (RBC) model to address environmental issues and design policies to tackle carbon emissions. Recently, there have been several extensions along this line of research. Dissou & Karnizova (2016) construct a multi-sector model to investigate the implications of different climate policies in the presence of multiple macroeconomic uncertainties. Along a different dimension, Annicchiarico & Di Dio (2015) studies the dynamics of an economy under different environmental policy regimes in a New Keynesian model with nominal and real uncertainty. Later, Annicchiarico & Diluiso (2019) set up a two-country E-DSGE model to study the international transmission of the business cycle. Our paper complements these studies by incorporating a full-fledged banking sector into an environmental DSGE model, which allows us to analyze the role of the banking sector in diverting lending towards clean production.

Second, our paper also related to the literature on financial transition risk as the economy moves towards cleaner production (Campiglio et al., 2018; de France, 2019; DOrazio & Valente, 2019; Carney, 2015; Ferrari & Nispi Landi, 2021; Punzi, 2018; van der Ploeg, 2020). Spiganti & Comerford (2020) is the first paper to explore the transition risk by embedding the carbon bubble in a macroeconomic model exhibiting a financial accelerator. They show that the macroeconomic policy can mitigate the carbon bubble effectively. On the flip side, there is evidence to utilize green quantitative easing (QE) and macro-prudential policy to support green financing. For example, Ferrari & Nispi Landi (2021) use an E-DSGE model to detect the effects of a temporary Green QE and show that this policy can be effective only if imperfect substitutability exists between green and brown bonds. Benmir & Roman (2020) and Diluiso et al. (2021) echo similar findings. Our

[4] See Annicchiarico et al. (2021) for a review on the topic of business cycles and the environmental policy.

paper differs from the previous studies by considering the impact of banks' differentiated lending rates to clean and dirty corporates on the transition to a green economy.

Finally, our paper also relates to the literature on the intersection between macroeconomic policy and environmental policy. For example, Economides & Xepapadeas (2018) employ an E-DSGE model to study the role of monetary policy under climate change and show that climate change does affect the design of the monetary policy. Diluiso et al. (2021) also use an E-DSGE model to calibrate the Euro Area economy to show that financial regulation can mitigate the severity of financial shocks and the green quantitative easing policy can stimulate the economy to a green one. Böhringer et al. (2016) and Shmelev & Speck (2018) study the fiscal policy and environment policy. Iovino et al. (2021) examine the relationship between corporate tax policy and carbon emissions. George et al. (2022) examine the role of sustainability-linked monetary policy through collateral constraint and interest rates on emissions and social welfare.

Our study is perhaps closely related to Carattini et al. (2021); Diluiso et al. (2021) who also incorporates the banking sector in the E-DSGE model with Gertler & Kiyotaki (2010); Gertler & Karadi (2011) framework where banks borrow from depositors and lend to borrowers. In contrast, our paper follows a richer banking framework (Benes & Kumhof, 2015; Barrdear & Kumhof, 2021) where banks fund loans by creating deposits (financing through money creation). This framework enables us to make more profound welfare assessments as emission-elastic lending rates impact lending and, as a consequence, deposit creation, which affects agents' lifetime expected utility (households' utility function depends on deposits). While Carattini et al. (2021); Diluiso et al. (2021) examines the macro-financial implications of financial sector regulation on the green transition risk, our paper instead focuses on recent initiative from commercial banks to offer preferential lending rates to corporates that engage in clean investments. To the best of our knowledge, an assessment of the impact of commercial banks led intermediation in capital reallocation to clean sectors is largely missing in the existing literature. Our paper is an attempt to fill this gap.

3 Model

Our model constitutes a banking sector that lends to capital investment agencies for financing capital purchases. We extend the framework in Benes & Kumhof (2015) to include clean and dirty capital investment agencies. Banks differentiate lending rates between clean and dirty capital investment funds through emission-elastic lending rates. Firms rent capital from both types of capital investment agencies and use them as inputs in production (George et al., 2022). The usage of dirty capital creates carbon emissions.

Household The household derives utility from external consumption habits and deposit holdings while facing disutility from labor supply and carbon emissions. A representative household seeks to maximise its lifetime expected utility:

$$\mathbb{E}_t \sum_{t=0}^{\infty} \beta^t u(c_t, n_t, \mathsf{d}_t, x_t), \tag{1}$$

where

$$u(c_t, n_t, \mathsf{d}_t, x_t) = z_t(1-\nu)\log(c_t - \nu c_{t-1}) - \mu_h \frac{n_t^{1+1/\eta_h}}{1+1/\eta_h} + \mu_d \log(\mathsf{d}_t) - \mu_x \frac{x_t^{1+1/\eta_x}}{1+1/\eta_x}. \tag{2}$$

c_t is a CES composite of all consumption varieties with elasticity of substitution ϵ, ν is the degree of habit persistence, n_t is labor supply, d_t is deposit holding and x_t is economy-wide aggregate carbon emission. μ_h, μ_d and μ_x are the respective weights of labor supply, deposit holdings and emissions in the utility function. The disutility from emissions results in households internalising environment externalities as in Acemoglu et al. (2012). η_h is the Frisch elasticity of labor supply. The budget of the household in period t is:

$$c_t + b_t + \mathsf{d}_t = r_t b_{t-1} + r_t^{\mathsf{d}} \mathsf{d}_{t-1} + w_t n_t - \tau_t^{ls} + D_t, \tag{3}$$

where b_t refers to government bonds, w_t is the real wage, τ_t^{ls} is the lump-sum tax paid to the government and D_t denotes aggregate dividends received by the household. Households own final goods firms, capital goods firms, clean and dirty capital investment agencies and banks. Thus, the overall dividends received by the households is:

$$D_t = \Pi_t^m + V_t + \zeta^k \sum_{j=\mathsf{c},\mathsf{d}} \mathsf{n}_{jt}^k + \zeta^b n_t^b + \Omega_t, \tag{4}$$

where Π_t^m is firm profit, V_t is the total profit from capital input production, $\zeta^k \sum_{j=\mathsf{c},\mathsf{d}} \mathsf{n}_{jt}^k$ refers to the proportion of net-worth from clean (c) and dirty (d) capital investment agencies received as dividends, $\zeta^b \mathsf{n}_t^b$ is the proportion of bank net-worth obtained as dividends and Ω_t is a lump-sum income from management of corporate bankruptcies.

The household budget constraint in eq. (3) also show bonds and deposits from period $t-1$ earn real interest at rate r_t and r_t^{d}, respectively. In our model, the real interest r_t^x from any asset or liability x corresponds to the nominal interest rate through fisher equation $r_t^x = \frac{i_{xt-1}}{\pi_t}$ where $\pi_t = \frac{P_t}{P_{t-1}}$ is the gross price inflation with P_t as the general price level in period t.

Household maximizes eq. (1) subject to eq. (3). The first-order conditions are listed below:

$$n_t : u_{n,t} = -u_{c,t} w_t, \tag{5}$$

$$\mathsf{d}_t : u_{\mathsf{d},t} = -u_{c,t} + \beta \mathbb{E}_t \frac{r_t^{\mathsf{d}}}{\pi_{t+1}} u_{c,t+1}, \tag{6}$$

$$b_t : u_{c,t} = \beta \mathbb{E}_t \frac{r_t}{\pi_{t+1}} u_{c,t+1}, \tag{7}$$

where $u_{q,t}$ denotes the marginal utility with respect to variable q in period t.

Capital goods firms Both clean and dirty capital stock are produced by capital goods firms, with the production immobile between the types of capital. Capital is indexed by $j \in \{c, d\}$ where c and d denote clean and dirty, respectively. Capital goods firms sell capital stock to capital investment agencies at competitive prices. Final goods firms then rent clean and dirty capital from capital investment agencies to produce output, leading to depreciation in both types of capital. Capital goods firms purchase back the depreciated capital from capital investment agencies and investment goods from final goods firms to produce new capital in the next period. As such, the two types of capital stock evolve as:

$$k_{ct} = (1-\delta)k_{ct-1} + I_{ct}, \tag{8}$$

$$k_{dt} = (1-\delta)k_{dt-1} + I_{dt}, \tag{9}$$

where k_{ct} is clean capital, k_{dt} is dirty capital and δ is the rate of capital depreciation that is similar across both types of capital.

The production of capital goods is subject to investments adjustment costs. The objective of a typical capital goods firm is to maximise the present discounted value of profits:

$$\max_{I_{ct}, I_{dt}} \mathbb{E}_t \sum_{t=0}^{\infty} M_{0,t} V_t, \tag{10}$$

where

$$V_t = \sum_{j=c,d} q_{jt} I_{jt} - I_{jt} \left[1 + \frac{\phi_I}{2} \left(\frac{I_{jt}}{I_{jt-1}} - 1 \right)^2 \right]. \tag{11}$$

$M_{0,t}$ is the stochastic discount factor, q_{jt} is the price of type j capital, I_{jt} refers to type j investment goods and ϕ_I determines the size of capital adjustment costs. The first-order conditions from the capital goods firm optimisation problem are:

$$I_{ct} : q_{ct} = 1 + \phi_I \left(\frac{I_{ct}}{I_{ct-1}} \right) \left(\frac{I_{ct}}{I_{ct-1}} - 1 \right) - \mathbb{E}_t M_{t,t+1} \phi_I \left(\frac{I_{ct+1}}{I_{ct}} \right)^2 \left(\frac{I_{ct+1}}{I_{ct}} - 1 \right), \tag{12}$$

$$I_{dt} : q_{dt} = 1 + \phi_I \left(\frac{I_{dt}}{I_{dt-1}} \right) \left(\frac{I_{dt}}{I_{dt-1}} - 1 \right) - \mathbb{E}_t M_{t,t+1} \phi_I \left(\frac{I_{dt+1}}{I_{dt}} \right)^2 \left(\frac{I_{dt+1}}{I_{dt}} - 1 \right), \tag{13}$$

where $M_{t,t+1} = \beta \frac{u_{c,t+1}}{u_{c,t}}$.

Capital investment agencies There are two types of capital investment agencies in our model; clean and dirty who purchase their specific type of capital from capital goods firms. The types of capital investment agencies are indexed by j with $j \in \{c, d\}$. Capital investment agencies receive rental income at real rate r^k_{jt} through renting out type j capital to final goods firms. The ex-post real return for type j capital in period t is given by:

$$ret^k_{jt} = \frac{r^k_{jt} + (1-\delta)q_{jt}}{q_{jt-1}}. \tag{14}$$

Capital investment agencies finance their purchase of capital using their net-worth and bank loans. Their balance sheet constraint is:

$$q_{jt}k_{jt} = \mathsf{n}^k_{jt} + l_{jt}, \tag{15}$$

where n^k_{jt} is the net-worth and l_{jt} is the loan amount. In period t, type j capital investment agencies enter a loan contract with banks to secure loans at nominal retail interest rate i^r_{jt}. Due to a bankruptcy risk measure ω^k_{jt+1}, the value of purchased type j capital in period $t+1$ changes to $\omega^k_{jt+1}k_{jt}$. The bankruptcy risk follows a log-normal distribution with $ln(\omega^k_{jt+1}) \sim N\left(1, {\sigma^k_{jt}}^2\right)$ with the cumulative and probability density functions denoted by $\mathfrak{F}^k_t(\omega^k_{jt+1})$ and $\mathfrak{f}^k_t(\omega^k_{jt+1})$, respectively. Capital investment agencies who draw the bankruptcy measure ω^k_{jt+1} below a cut-off $\overline{\omega}^k_{jt+1}$ are unable to pay the interest charges and become bankrupt. The ex-ante bankruptcy cut-off for a type j capital investment agency is:

$$\overline{\omega}^k_{jt} = \frac{r^r_{jt}l_{jt-1}}{ret^k_{jt}q_{jt-1}k_{jt-1}}. \tag{16}$$

In period $t+1$, only proportion $\left[1 - \mathfrak{F}^k_t(\overline{\omega}^k_{jt+1})\right]$ of type j capital investment agencies pay the committed retail interest rate. The rest enter bankruptcy. This gives rise to banks' ex-ante zero profit constraint that pins down retail rates as:

$$\mathbb{E}_t\tilde{r}^l_{jt+1}l_{jt} = \mathbb{E}_t\left\{\left[1 - \mathfrak{F}^k_t(\overline{\omega}^k_{jt+1})\right]r^r_{jt}l_{jt} + (1-\xi)\int_0^{\omega^k_{jt+1}} ret^k_{jt+1}\omega^k_{jt+1}q_{jt}k_{jt}\mathfrak{f}^k_t(\omega^k_{jt+1})d\omega^k_{jt+1}\}\right\}, \tag{17}$$

where the wholesale real interest payments (charged to notional zero-risk capital investment agencies) at rate $\tilde{r}^l_{jt+1}$ equal the expected payoff from lending. The first term on the right-hand side refers to interest income from capital investment agencies who are able to pay the pre-committed retail rate. The second term pertains to the cash-flow from bankruptcy where banks recover only $(1-\xi)$ portion of the return on capital investment.

The remaining ξ portion is paid out to households as fees for managing the bankruptcy (see Ω_t in eq. (4)).

We re-write the zero expected bank profit condition (eq. (17)) as:

$$\mathbb{E}_t \left\{ (\Gamma_{jt+1} - \xi G_{jt+1}) \frac{ret^k_{jt+1}}{\tilde{r}^l_{jt+1}} \frac{q_{jt}k_{jt}}{\mathsf{n}^k_{jt}} - \frac{q_{jt}k_{jt}}{\mathsf{n}^k_{jt}} + 1 \right\} = 0, \tag{18}$$

where the share of the banks monitoring cost in the capital earnings is ξG_{jt+1} with $G_{jt+1} = \int_0^{\overline{\omega}^k_{jt+1}} \omega^k_{jt+1} \mathfrak{f}^k_t(\omega^k_{jt+1}) d\omega^k_{jt+1}$. $\Gamma_{jt+1} \equiv \int_0^{\overline{\omega}^k_{jt+1}} \omega^k_{jt+1} \mathfrak{f}^k_t(\omega^k_{jt+1}) d\omega^k_{jt+1} + \overline{\omega}^k_{jt+1} \int_{\overline{\omega}^k_{jt+1}}^{\infty} \mathfrak{f}^k_t(\omega^k_{jt+1}) d\omega^k_{jt+1}$ is the banks share in type j capital earnings. This implies that the share of type j capital investment agencies in the capital earnings equal $1 - \Gamma_{jt+1}$. Thus, type j capital investment agency seeks to maximise its profits:

$$\max_{k_{jt}\overline{\omega}^k_{jt+1}} \mathbb{E}_t \left\{ (1 - \Gamma_{t+1}) \frac{ret^k_{jt+1}}{\tilde{r}^l_{jt+1}} \frac{q_{jt}k_{jt}}{\mathsf{n}^k_{jt}} \right\}, \tag{19}$$

subject to eq. (18). From the first-order conditions, we obtain:

$$\mathbb{E}_t \left\{ (1 - \Gamma_{ct+1}) \frac{ret^k_{ct+1}}{\tilde{r}^l_{ct+1}} + \frac{\Gamma'_{ct+1}}{\Gamma'_{ct+1} - \xi G'_{ct+1}} \left[\frac{ret^k_{ct+1}}{\tilde{r}^l_{ct+1}} (\Gamma_{ct+1} - \xi G_{ct+1}) - 1 \right] \right\} = 0, \tag{20}$$

$$\mathbb{E}_t \left\{ (1 - \Gamma_{dt+1}) \frac{ret^k_{dt+1}}{\tilde{r}^l_{dt+1}} + \frac{\Gamma'_{dt+1}}{\Gamma'_{dt+1} - \xi G'_{dt+1}} \left[\frac{ret^k_{dt+1}}{\tilde{r}^l_{dt+1}} (\Gamma_{dt+1} - \xi G_{dt+1}) - 1 \right] \right\} = 0, \tag{21}$$

where annotation of $'$ indicates the first-order derivative of the variable with respect to ω^k_{jt+1}.

Finally, the net-worth of type j capital investment agencies in eq. (15) evolves as:

$$\mathsf{n}^k_{jt} = \tilde{r}^l_{jt}\mathsf{n}^k_{jt} + (ret^k_{jt}(1 - \xi G_t) - \tilde{r}^l_{jt}) q_{jt-1}k_{jt-1} - \zeta^k \mathsf{n}^k_{jt} + \mathfrak{L}_{jt}, \tag{22}$$

where $\mathfrak{L}_{jt}$ refers to the realised bank loss which become capital investment agencies' gain.

Banks The banks issue loans to capital investment funds (both types) and provides deposits to households. The balance sheet of a representative bank is given by:

$$l_t = \mathsf{d}_t + \mathsf{n}^b_t, \tag{23}$$

where $l_t = l_{ct} + l_{dt}$ is the total loans issued and n^b_t is the banks' net-worth. A representative bank seeks to maximise the pre-dividend profits from lending:

$$\Pi^b = \max_{l_{ct}, l_{dt}} \mathbb{E}_t \left\{ \omega^b_{t+1} \sum_{j=c,d} \tilde{r}^l_{jt+1} l_{jt} - r^{\mathsf{d}}_{t+1} \mathsf{d}_t - \mathfrak{L}_{jt+1} - \chi l_t \mathfrak{F}^b_t(\overline{\omega}^b_{t+1}) \right\}, \tag{24}$$

where the returns from lending are subject to solvency risk measure ω^b_{t+1}, which follows a log-normal distribution. Hence, we have $ln(\omega^b_{t+1}) \sim N\left(1, \sigma^{b^2}\right)$. Banks are unable to maintain Minimum Capital Adequacy Requirements (MCAR) if their solvency risk measure falls below a cut-off $\overline{\omega}^b_{t+1}$, leading to a penalty payment of $\chi l_t \mathfrak{F}^b_t(\overline{\omega}^b_{t+1})$. The cut-off solvency risk measure in period t is:

$$\overline{\omega}^b_t = \frac{r^{\mathsf{d}}_t \mathsf{d}_{t-1} + \mathfrak{L}_{jt}}{(1-\gamma_{t-1}) \sum_{j=c,k} \tilde{r}^l_{jt} l_{jt-1}}, \tag{25}$$

where γ_{t-1} is the MCAR ratio set by the central bank in period $t-1$.

Net-worth in eq. (23) evolves as:

$$\mathsf{n}^b_t = \sum_{j=c,d} \tilde{r}^l_{jt} l_{jt-1} - r^{\mathsf{d}}_t \mathsf{d}_{t-1} - \mathfrak{L}_{jt} - \chi \mathfrak{F}^b_t(\overline{\omega}^b_t) - \zeta^b \mathsf{n}^b_t, \tag{26}$$

where ζ^b is the proportion of banks' net-worth paid out as dividends to households and χ is the MCAR penalty parameter.

Banks maximise eq. (24) subject to eq. (23). The resulting first-order conditions are:[5]

$$l_{ct} : \mathbb{E}_t \left\{ \tilde{r}^l_{ct+1} - r^{\mathsf{d}}_{t+1} - \chi \left(\mathfrak{F}^b_t(\overline{\omega}^b_{t+1}) + l_t \frac{\partial \mathfrak{F}^b_t(\overline{\omega}^b_{t+1})}{\partial l_{ct}} \right) \right\} = 0, \tag{27}$$

$$l_{dt} : \mathbb{E}_t \left\{ \tilde{r}^l_{dt+1} - r^{\mathsf{d}}_{t+1} - \chi \left(\mathfrak{F}^b_t(\overline{\omega}^b_{t+1}) + l_t \frac{\partial \mathfrak{F}^b_t(\overline{\omega}^b_{t+1})}{\partial l_{dt}} \right) \right\} = 0, \tag{28}$$

[5]The detailed expressions can be obtained in Appendix A.

Emission-elastic lending rate Banks differentiate lending rates to clean and dirty capital investment agencies through emission-elastic lending rate. When emission growth exceeds the target, banks lower nominal clean capital lending rates, $\tilde{i}^{l}_{ct}$ from the market-determined rate i^{l}_{ct}. The emission-elastic lending rate coefficient determines the response intensity of $\tilde{i}^{l}_{ct}$ to emission growth. We define the realised nominal wholesale lending rates differentiated with emission-elastic treatment as:

$$\tilde{i}^{l}_{ct} = i^{l}_{ct} \exp\left[-\phi_x \left(\frac{x_t}{x_{t-1}} - 1\right)\right], \tag{29}$$

$$\tilde{i}^{l}_{dt} = i^{l}_{dt}, \tag{30}$$

where x_t is domestic carbon emission and ϕ_x as the emission-elastic lending rate coefficient. If $\phi_x = 0$, clean and dirty capital lending rates are equal (no differentiated lending rates between different capital types). On the other hand, $\phi_x > 0$ implies that clean capital investments agencies are offered a lending rate lower than the market-determined rate i^{l}_{ct} when emissions increase. In other words, a positive ϕ_x creates a spread between the dirty and clean capital lending rates. The market distortion from emission-elastic lending rates causes asymmetric effects on the loan demand from clean and dirty capital investment agencies. Lower borrowing costs can encourage clean capital investment agencies to finance more clean capital. In short, emission-elastic lending rates endogenously expands clean capital when emissions growth exceeds target.

Final goods firms A final goods firm that produces variety i output uses labor $n_t(i)$ and capital $k_{t-1}(i)$ as inputs:

$$y_t(i) = A_t \left[1 - \Lambda\left(m_t\right)\right] n_t(i)^{1-\alpha} k_{t-1}(i)^{\alpha}, \tag{31}$$

where $\Lambda\left(m_t\right)$ is the damage function of global carbon emission stock m_t which takes the functional form:

$$\Lambda\left(m_t\right) = \gamma_0 + \gamma_1 m_t + \gamma_2 m_t^2. \tag{32}$$

$k_t(i)$ in eq. (31) is a CES composite of clean and dirty capital inputs for variety i, with A_c as the productive efficiency of the clean capital. The two capital inputs are imperfect substitutes with φ denoting the degree of substitution elasticity.

$$k_t(i) = [\upsilon^{1/\varphi} k_{dt}(i)^{1-1/\varphi} + (1-\upsilon)^{1/\varphi}(A_c k_{dt}(i))^{1-1/\varphi}]^{\frac{\varphi}{\varphi-1}} \tag{33}$$

Firm-level carbon emissions $x_t(i)$ arise from the usage of dirty capital inputs alone. Hence, we have:

$$x_t(i) = [1 - \vartheta_t(i)]\, \phi_d k_{dt-1}(i), \tag{34}$$

where $\vartheta_t(i)$ is the effort of final goods firm at carbon emissions abatement and $\phi_d > 0$ shows the emissions per unit of dirty capital input.

Final goods firm seeks to maximise its profits:

$$\Pi_t^m(i) = \max_{n_t(i), k_{dt}(i), k_{ct}(i), \vartheta_t(i)} y_t(i) - w_t n_t(i) - r_{dt}^k k_{dt-1}(i) - r_{ct}^k k_{ct-1}(i) - \tau_t^x x_t(i) - \mathcal{C}_t^A(i), \tag{35}$$

where τ_t^x is the tax on carbon emission and $\mathcal{C}_t^A(i)$ is the cost of emission abatement that depends on the firm's abatement effort and choice of dirty capital usage. Hence, we have

$$\mathcal{C}_t^A(i) = \phi_1 \vartheta_t(i)^{\phi_2} k_{dt-1}(i) \tag{36}$$

Final goods firm maximizes eq. (35) subject to eqs. (31), (34) and (36). The resulting first-order conditions are:

$$n_t(i) : (1-\alpha)\,\frac{y_t(i)}{n_t(i)} = \frac{w_t}{mc_t(i)}, \tag{37}$$

$$k_{ct-1}(i) : \alpha\,(1-\upsilon)^{1/\varphi}\frac{y_t(i)}{k_{ct-1}(i)}\left(\frac{k_{ct-1}(i)}{k_{jt-1}(i)}\right)^{-1/\varphi} = \frac{r^k_{ct}}{mc_t(i)}, \tag{38}$$

$$k_{dt-1}(i) : \alpha\,\upsilon^{1/\varphi}\frac{y_t(i)}{k_{dt-1}(i)}\left(\frac{k_{dt-1}(i)}{k_{jt-1}(i)}\right)^{-1/\varphi} = \frac{\tilde{r}^k_{dt}(i)}{mc_t(i)}, \tag{39}$$

$$\vartheta_t(i) : \tau^x_t\phi_d = \phi_1\phi_2\vartheta_t(i)^{\phi_2-1}, \tag{40}$$

where $mc_t(i)$ is the firm's marginal cost and $\tilde{r}^k_{dt}(i) = r^k_{dt} + \tau^x_t\phi_d\,[1-\vartheta_t(i)] + \phi_1\vartheta_t(i)^{\phi_2}$ is the abatement cost adjusted rent accrued to dirty capital. The adjusted rental costs on dirty capital ensure firms internalise environment externality. eq. (40) reveals that all firms choose similar levels of abatement effort. As a consequence, the adjusted dirty capital rent is also similar across firms. Taken together, all four optimality conditions imply that all firms make similar choices on labor, clean capital, dirty capital and abatement efforts. Hence, we can drop the (i) index.

Final goods prices follow Calvo (1983) style stickiness, with a fraction $(1-\theta)$ of firms re-optimising their prices every period. The optimal price is set in accordance with:

$$\tilde{\pi}_t = \frac{\epsilon}{\epsilon-1}\frac{\sum_{h=0}^{\infty}\theta^h\mathbb{E}_t\mathcal{Q}_{t,t+h}\left(\frac{p_t}{p_{t+h}}\right)^{-\epsilon}y_{t+h}mc_{t+h|t}}{\sum_{h=0}^{\infty}\theta^h\mathbb{E}_t Q_{t,t+h}\left(\frac{p_t}{p_{t+h}}\right)^{1-\epsilon}y_{t+h}}, \tag{41}$$

where $\tilde{\pi}_t = \frac{\tilde{p}_t}{p_t}$ is the optimal price divided by general price, ϵ is the elasticity of substitution between output varieties and $Q_{t,t+h}$ is the stochastic discount factor. Finally, the gross price inflation is pinned down by:

$$1 = \theta\pi_t^{\epsilon-1} + (1-\theta)\tilde{\pi}_t^{1-\epsilon}. \tag{42}$$

Government The receipts of the government include lump-sum taxes collected from households, emissions taxes from firms and the penalty payments from banks that violate MCAR. Government's budget constraint is:

$$\tau^{ls}_t + \tau^x_t x_t + \mathcal{T}^b_t = g_t. \tag{43}$$

$\mathcal{T}_t^b = \chi l_t \mathfrak{F}_t^b(\overline{\omega}_{t+1}^b)$ is the penalty payment from MCAR violation. g_t is the government purchase of consumption goods that is a fraction of steady-state GDP, $g_t = s_g \bar{y}$.

The monetary policy follows the below rule for inflation and output targeting:

$$i_t = (i_{t-1})^{\rho_i} \left[\frac{1}{\beta} \left(\frac{\pi_t \pi_{t+1} \pi_{t+2} \pi_{t+3}}{\pi^4} \right)^{\phi_\pi} \left(\frac{y_t}{\bar{y}} \right)^{\phi_y} \right]^{1-\rho_i}, \tag{44}$$

where $\pi_t \pi_{t+1} \pi_{t+2} \pi_{t+3}$ is the annualised forward looking inflation. ρ_i is the smoothing parameter for the interest rate. ϕ_π and ϕ_y are the inflation and output feedback coefficients, respectively.

The MCAR ratio is set in accordance with the below macroprudential rule:

$$\gamma_t = \bar{\gamma} \left(\frac{l_t}{\bar{l}} \right)^{\phi_l}, \tag{45}$$

where ϕ_l is the loan feedback coefficient. A positive ϕ_l implies MCAR ratio γ_t is allowed to rise with an increase in loan stock from its respective steady-state.

Equilibrium In equilibrium, the final goods market clears:

$$y_t = c_t + g_t + \mathcal{C}_t^A + \sum_{j \in \{c,d\}} I_{jt} \left[1 + \frac{\phi_I}{2} \left(\frac{I_{jt}}{I_{jt-1}} - 1 \right)^2 \right]. \tag{46}$$

Aggregation of all varieties of output in eq. (31) yields:

$$s_t y_t = A_t \left[1 - \Lambda(m_t) \right] n_t^{1-\alpha} k_{t-1}^{\alpha}, \tag{47}$$

where $s_t = \int_0^\infty \left(\frac{p_t(i)}{p_t} \right)^\epsilon di$ is the price dispersion that is pinned down by:

$$s_t = (1-\theta) \tilde{\pi}_t^{-\epsilon} + \theta \pi_t^{\epsilon} s_{t-1}. \tag{48}$$

Exogenous shocks We consider three exogenous shocks in our model: shocks to labour productivity A_t (supply shock), consumption preference z_t (demand shock) and carbon tax τ_t^x (environmental policy shock). Vector $\mathbf{e}_t$ comprise the three shocks which follow an AR(1) process:

$$\ln(\mathbf{e}_t) = \rho_{\mathbf{e}}\ln(\mathbf{e}_t) + (1-\rho_{\mathbf{e}})\ln(\bar{\mathbf{e}}) + \varepsilon_{\mathbf{e}}, \quad \varepsilon_{\mathbf{e}} \sim N(0, \sigma_{\mathbf{e}}^2) \tag{49}$$

4 Parameterization

We calibrate our model using parameter values from past literature, at the quarterly frequency. Table 1 shows the parameter values. In line with Smets & Wouters (2003), the discount factor β is 0.99, the habit persistence ν equals 0.7, and the Frisch elasticity η_h is set at 1. Following George et al. (2022), capital share in production function α is 0.33, capital depreciation rate δ is 0.02, investment adjustment cost ϕ_I is 2, the elasticity of substitution (EoS) between goods [6] ϵ equals 6 and the fraction of firms who cannot reset price θ is fixed at 0.75. The weight of labor hours ψ_h and deposits ψ_d in the utility function are in line with Benes & Kumhof (2015). The functional form of carbon emission in household utility is similar to Pan et al. (2021). The carbon emissions weight in the utility function μ_x is set to 1. We discuss the emission disutility parameter in section 7. The steady-states government spending to GDP ratio is 18% (Barrdear & Kumhof, 2021).

With regard to the E-DSGE parameters, we follow Annicchiarico & Di Dio (2015); George et al. (2022); Punzi (2018). The abatement cost parameters (ϕ_1[7] and ϕ_2), the damage function parameters (γ_1 and γ_2) and the steady-state pollution decay rate $\overline{\vartheta}$ follow Annicchiarico & Di Dio (2015) who calibrate the parameters to the US economy. We follow George et al. (2022) to set the dirty capital weight υ in the CES composite of capital used by firms, the elasticity of substitution between capital types φ and the carbon emissions per unit of dirty capital ϕ_d. The steady-states of carbon stock $\overline{m}$ and damage function $\Gamma(\overline{m})$ at 800 and 0.61%, respectively are close to the estimates of Annicchiarico & Di Dio (2015). The steady-state of a carbon tax is 21.66%, which is in line with George et al. (2022). Following Punzi (2018), we assume the productive efficiencies of clean capital and dirty capital are equal, i.e. $A_c = 1$. We discuss the productive efficiency

[6] We explore the sensitivity of the main results to smaller EoS values in Appendix B.

[7] We conduct a sensitivity analysis of the emission-elastic lending rate results pertaining to the abatement coefficient ϕ_1. The results are reported in Appendix C.

Table 1: Calibration parameterization

Parameter	Value	Description
NK parameters		
β	0.99	Discount factor
ν	0.70	Habit persistence
η_h	1	Frisch elasticity
ψ_h	0.9524	Labor disutility
ψ_d	0.0042	Deposit utility
ψ_x	1	Carbon emission disutility
η_x	1	Carbon emission elasticity
α	0.33	Capital share in production function
δ	0.02	Capital depreciation rate
ϕ_I	2	Investment adjustment cost
ϵ	6	Elasticity of substitution between goods
θ	0.75	Fraction of firms with fixed price
Environmental parameters		
ϕ_1	0.185	Abatement cost parameters
ϕ_2	2.8	
γ_0	0.001395	Damage function parameters
γ_1	-6.6722E-06	
γ_2	1.4647E-08	
ϑ_t	1-0.997	Pollution decay
υ	0.5	Dirty capital parameter in capital function
φ	2	Elasticity of substitution between clean and dirty capital
ϕ_d	0.09	Emission per unit
A_c	1	The relative productive efficiency of clean capital
Banking sector parameters		
χ	0.0033	Bankruptcy MCAR penalty ratio
δ^b	0.0146	Bank net worth dividend ratio
Policy parameters		
ρ_i	0.7	Interest rate smoothing
ϕ_π	2	Inflation feedback
ϕ_y	0.25	Output feedback
ϕ_l	6	Loan feedback
$\bar{\gamma}$	0.08	Bank MCAR

of clean capital in section 7.

The calibration of the monetary policy coefficients (ρ_i, ϕ_π and ϕ_y) and macro-prudential policy parameter (ϕ_l) using Benes & Kumhof (2015). In accordance with the Basel-III mandates, we set the steady-state of capital requirement ratio as $\bar{\gamma} = 0.08$. Furthermore, we follow Benes & Kumhof (2015) to set the bankruptcy MCAR penalty cost χ and bank net worth dividend ratio δ^b at 0.0033 and 0.146, respectively.

The shock parameters reported in table 2 are calibrated to match the standard deviations, autocorrelations and cross-correlations of the US macroeconomic data for the period 1990Q1-2020Q1. Table 3 and Table 4 compare the data moments and the implied moments from a second order perturbation of the model using Dynare 4.6.4.[8]. It is observed that model moments can reasonably match their data counterparts for most of the variables.

Table 2: Shock parameterization

	Autocorrelation	Standard error
Technology shock (A_t)	0.80	0.011
Consumption demand shock (z_t)	0.60	0.016
Carbon tax shock (τ_t^x)	0.93	0.24

Table 3: Standard deviation and autocorrelation

	Standard deviation		Autocorrelation	
	Data	Model	Data	Model
GDP	2.61	1.87	0.32	0.49
Consumption	2.09	2.15	0.36	0.38
Investment	7.43	5.80	0.22	0.33
Inflation	1.01	1.29	0.25	0.47
Policy rate	2.06	2.00	0.79	0.80
Net worth (clean)	6.11	5.07	0.62	-0.03
Net worth (dirty)	6.11	6.18	0.62	-0.03
Carbon emission	2.56	2.55	-0.03	-0.02

[8]The data are achieved from the FRED database. The proxy variable for the risk-free rate (policy rate) is the 3-month treasury bill rate. Due to data availability, we simply assume the clear and dirty firms have the same net worth. The net worth of clean/dirty firms is represented by the non-financial corporate net worth.

Table 4: Cross-correlations

Variable pairs	Cross-correlations	
	Data	Model
GDP, consumption	0.9479	0.8944
GDP, investment	0.7995	0.6692
GDP, inflation	0.4852	-0.8246
GDP, policy rate	0.5383	-0.6760
GDP, net worth (clean)	0.7199	0.3670
GDP, net worth (dirty)	0.7199	0.3212
GDP, carbon emission	0.7005	0.0389

Table 5 shows the variance decomposition of the shocks. The technology shock explains most of the volatility in all the key variables except for consumption and carbon emission. Consumption demand shock account most for the volatility in consumption whereas carbon tax shock explains more of emission volatility.

Table 5: Variance decomposition (%)

	Technology	Consumption demand	Carbon tax
GDP growth	79.49	20.05	0.46
Consumption growth	41.18	57.88	0.94
Investment growth	76.02	14.64	9.33
Inflation	99.06	0.85	0.09
Policy rate	90.07	9.19	0.75
Net worth growth (clean)	80.07	19.37	0.56
Net worth growth (dirty)	51.94	12.36	35.69
Carbon emission growth	1.19	0.19	98.62

5 Emission-elastic lending rate: Social welfare vis-á-vis bank profits

This section discusses the improvements in bank profits and social welfare when banks adopt emission-elastic lending rates. To this end, we define bank profit as Π_t^b in eq. (24) and social welfare as the discounted value of the households lifetime expected utility:

$$\mathcal{W}_t = \mathbb{E}_t \sum_{j=0}^{\infty} \beta^t u(c_{t+j}, n_{t+j}, \mathsf{d}_{t+j}, x_{t+j}). \tag{50}$$

Our analysis involves two steps. First, we search for the value of ϕ_x that delivers the maximum bank profit. We consider the range $\phi_x \in [0, 2]$ for the search at increments of 0.01. Second, we search for ϕ_x that maximizes social welfare over the same range $\phi_x \in [0, 2]$ as in the first step. We used the unconditional mean of bank profit and social welfare that Dynare 4.6.4 reports at order 2 for the grid searches. The ϕ_x values delivering the highest bank profit and social welfare are reported as competitive and socially optimal coefficients, respectively. If the emission-elastic lending rates improve welfare and profit, the competitive and socially optimal ϕ_x would be positive. For ease of understanding, we define gains in welfare and profit as the percentage change from the scenario of no emission-elastic lending rates, i.e. when $\phi_x = 0$.

Table 6: Social welfare and bank profit with emission-elastic lending rate

	ϕ_x	Profit gain (%)	Welfare gain (%)
Competitive	1.51	0.0104	-0.0051
Socially optimal	0.25	0.0034	0.0004

Note: Welfare/profit gain is the percentage change in welfare/profit compared to scenario with no premium. The effect is calculated as $100 \times (V_{\phi_x=optimal} - V_{\phi_x=0})/V_{\phi_x=0}$, $V \in \{\text{Profits, Welfare}\}$ using moments reported by Dynare 4.6.4 at order=2. A negative value indicates welfare/profit loss.

Table 6 shows the findings of our analysis when the economy simultaneously faces technology and consumption demand shocks. From our grid searches, we find the competitive ϕ_x equals 1.51 (value of ϕ_x that maximises bank profit). Banks' profits rise by about 0.01% when commercial banks are allowed autonomy in setting the emission-elastic lending rate coefficient, i.e. competitive ϕ_x. By contrast, the social welfare of the economy decreases by 0.0051% at competitive ϕ_x as compared to the baseline scenario with ϕ_x equal to zero. These results imply a potential trade-off between welfare improvement and profit maximization when the decision of setting ϕ_x is delegated to commercial banks.

Socially optimal ϕ_x in Table 6 is the value of ϕ_x that maximises social welfare in our grid search. Both commercial banks' profits and social welfare increase with socially optimal ϕ_x as compared to the baseline (see the second row in Table 6). Compared to competitive ϕ_x, the socially optimal ϕ_x is much smaller in magnitude, about one-sixth of the former. The smaller gain in bank profit accompanying socially optimal ϕ_x as compared to competitive ϕ_x implies a potential positive relationship between ϕ_x and

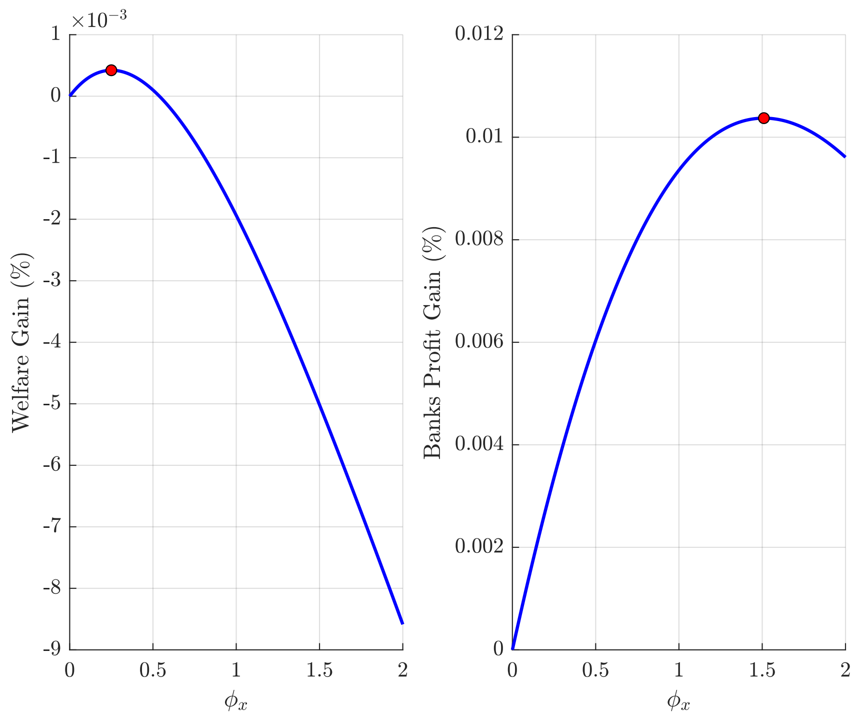

Figure 1: Dynamic plot of welfare gain and bank profit gain

banks' profits. To further investigate the relationship between the emission-elastic lending rate coefficient and the gains in banks' profits and social welfare, we plot the gains in social welfare and banks' profits corresponding to the ϕ_x values.

Figure 1 shows the results. We find that the gains in bank profits and social welfare initially rise with ϕ_x and fall after ϕ_x reaches competitive and socially optimal values, respectively. Interestingly, a rise in ϕ_x causes only marginal improvements in social welfare (the left panel). In fact, welfare loss arises for values of ϕ_x beyond 0.54. In contrast, there are improvements in bank profits for all values of ϕ_x considered (see second panel) with the maximum gain in bank profit at $\phi_x = 1.51$. Thus, the emission-elastic lending rate coefficient creates a trade-off between improvement in social welfare and bank profits.

Individual shocks Table 6 shows a positive gap between competitive and socially optimal ϕ_x when both shocks are simultaneously present. We next examine the intensity of the gaps with respect to individual shocks. We conduct grid searches as before to obtain the competitive and socially optimal ϕ_x in the presence of individual shocks. Table 7 reports the coefficients and the accompanying gains in bank profits and social welfare for technology and consumption preference shocks in panels A and B, respectively. The positive gap between competitive and socially optimal ϕ_x persists for both shocks, with the gap wider when the economy is subject to the consumption preference shock.[9] We also find differences between the individual shocks in the gains to bank profits and social welfare. First, the magnitude of the bank profit and social welfare gains under technology shock largely resembles that of the simultaneous shocks resulting in table 6. This is intuitive given the fact that technology shock largely explains the volatility of key variables (see table 5). Second, the consumption preference shock results in banks suffering a profit loss with socially optimal ϕ_x. This is in contrast to the technology shock where socially optimal ϕ_x accompanies an increase in bank profits. Section 6 elaborates more on the mechanics that drive the differences in bank profits and social welfare associated with individual shocks in the context of competitive and socially optimal ϕ_x.

Table 7: Social welfare and bank profit with emission-elastic lending rate: Individual shocks

	ϕ_x	Profit gain (%)	Welfare gain (%)
Panel A: Technology shock			
Competitive	1.20	0.0058	-0.0021
Socially optimal	0.30	0.0026	0.0005
Panel B: Consumption preference shock			
Competitive	4.54	0.0069	-0.0057
Socially optimal	-0.02	-0.0001	0.0005

Note: Welfare/profit gain is the percentage change in welfare/profit compared to a scenario with no premium. The effect is calculated as $(V_{\phi_x=optimal} - V_{\phi_x=0})/V_{\phi_x=0}$, $V \in \{\text{Profits, Welfare}\}$ using moments reported by Dynare 4.6.4 at order=2. A negative value indicates welfare/profit loss.

6 Equilibrium dynamics

This section reports the dynamic properties of emission-elastic lending rates using; a) *Baseline*: Commercial banks do not set an emission-elastic lending rate, i.e. $\phi_x = 0$, b) *Competitive* ϕ_x: The emission-elastic lending rates are determined by commercial banks, c) *Socially optimal* ϕ_x: Social planner sets the value of the emission-elastic lending

[9]The dynamic plots of gains in welfare and bank profit with respect to individual shocks are shown in Appendix D.

coefficient ϕ_x. We use the values of competitive and socially optimal ϕ_x from table 7 for the simulations.

Technology shock Figure 2 shows the impulse responses of key variables following a positive one standard deviation technology shock. The solid blue line represents the responses in the baseline scenario ($\phi_x = 0$), the black dotted line corresponds to socially optimal ϕ_x, and the red dashed line pertains to competitive ϕ_x.

We first discuss the dynamics in the baseline regime (solid blue line). An exogenous rise in productivity increases GDP. The increase in the aggregate supply of goods leads to deflation, causing the nominal policy rate to drop in response. As a consequence, returns from capital rentals improve for capital investment agencies (corporates), leading to a decline in the share of capital investment agencies (both clean and dirty) in bankruptcy. Furthermore, the dip in interest rates induces both types of capital investment agencies to borrow more. As such, both types of capital lending rise, albeit symmetrically. The financing through the money creation channel (Benes & Kumhof, 2015; Barrdear & Kumhof, 2021) causes bank deposits to rise in tandem with bank loans. Both types of capital and investment also expand symmetrically. The increase in dirty capital worsens carbon emissions.

With emission-elastic lending rates (black dotted and red dashed lines), emission growth stemming from technology shock causes the spread between dirty and clean capital lending rates to widen. Contrary to the baseline, emission-elastic lending rates create asymmetrical responses in the equilibrium quantity of clean and dirty capital loans. The dip in the clean capital lending rate, owing to the emission-elastic lending rate coefficient, makes clean capital loans cheaper than dirty capital loans. Consequently, a strong demand for clean capital loans arises, leading to larger bank profits. Such a surge in bank profits stemming from the strong clean capital loan demand likely explains higher intensity of ϕ_x in the competitive regime. In fact, the hump shape in clean lending, which occurs a few periods post the shock, becomes more pronounced with a competitive ϕ_x. In contrast, competitive ϕ_x lowers the persistence in dirty capital loans' response (hump shape disappears). Such asymmetric lending responses result in environmentally favorable implications on capital and investment. Clean capital increases more than dirty capital. A similar dynamic occurs in clean and dirty investments. Consequently, carbon emissions rise by less.

Although environmentally feasible, emission-elastic lending rates do not elicit financial stability. With emission-elastic leading rates ($\phi_x > 0$), clean capital loan volatility makes aggregate bank lending more volatile. Bank deposits are also more unstable on account of the financing through money creation channel (Benes & Kumhof, 2015). Volatility in deposits creates duress for the households as the lifetime utility function of the households comprises deposits (see eq. (2)). In other words, the household's adversity from deposit volatility associated with emission-elastic lending rates causes the social planner to opt for a smaller ϕ_x (socially optimal ϕ_x). Hence, the socially optimal ϕ_x is less than the competitive ϕ_x.

As described previously in section 5, there are only marginal social welfare improvements with socially optimal ϕ_x. Then, a natural question would be why such welfare improvements arise despite the deposit volatility associated with emission-elastic lending rates. The likely explanation lies in the other determinant of households' utility - emissions. From eq. (1), we see that households suffer disutility from emissions. Emission-elastic lending rates ($\phi_x > 0$) help reduce emissions, improving social welfare. The benefit from lower emissions outweighs the costs of higher deposit volatility, causing the social planner to opt for a small yet positive ϕ_x.

Consumption demand shock Figure 3 shows the impulse responses following a positive one standard deviation expansionary consumption demand shock. In the baseline, the increase in aggregate demand following an exogenous rise in consumption demand results in inflation. GDP expands with the consumption increase. Nominal interest rate rises as a response to inflation. The consumption rise coupled with high-interest rates crowds out investment and capital (both types). Hence, emissions decline. The drop in investment also lowers loan demand. Hence, both bank deposits and loans drop initially after the shock.

The rise in nominal rates causes clean and dirty capital lending rates to increase in equilibrium. In the baseline scenario, the responses are similar across both lending rates.

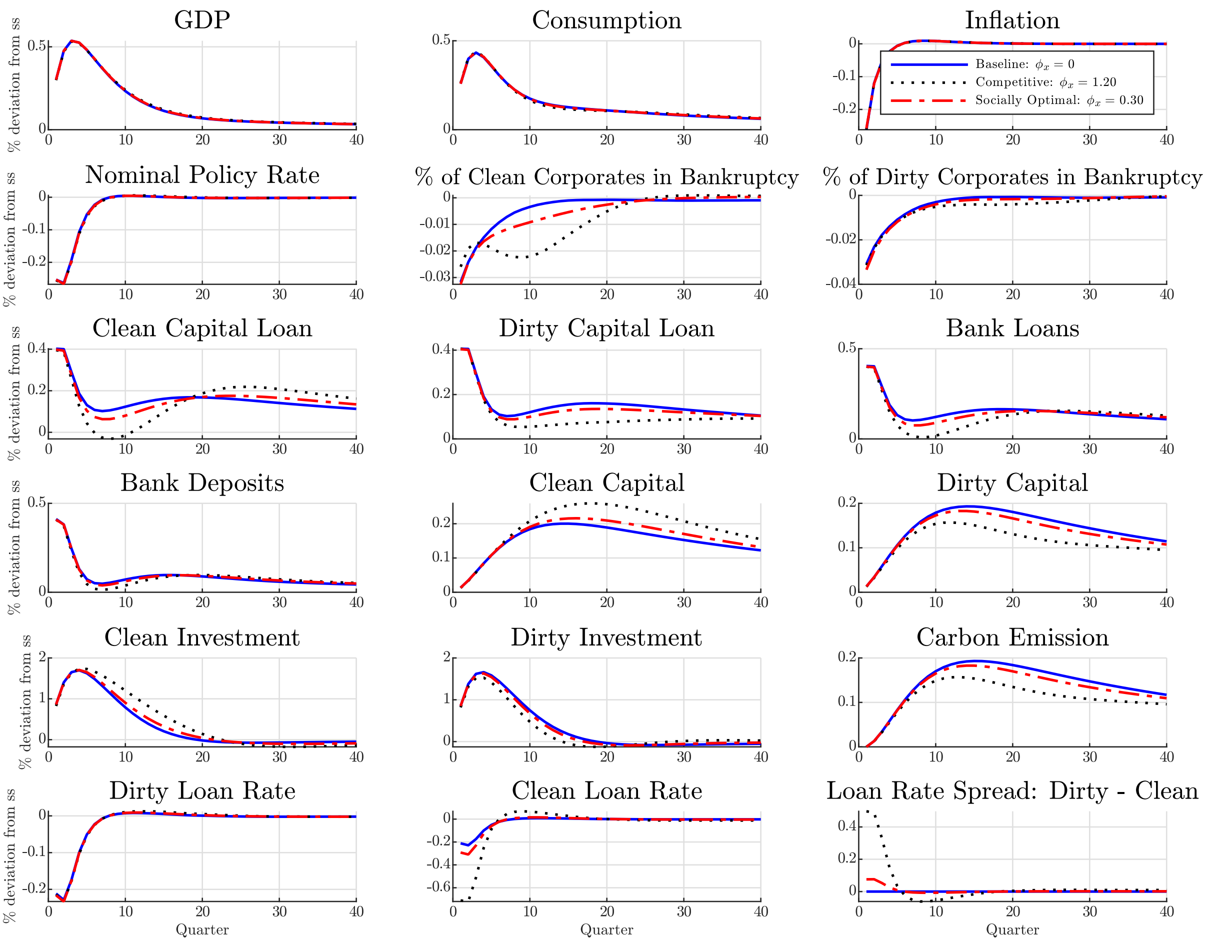

Figure 2: Technology shock

Note: This figure shows the impulse responses of key variables following a positive one standard deviation technology shock.

These changes in the context of emission-elastic lending rates as competitive ϕ_x, which is greater than zero, causes the spread between dirty and clean capital lending rates to narrow. In other words, the negative emission growth causes the emission-elastic clean capital lending rate to rise more than the dirty capital lending rate. Banks find emission-elastic lending rates more profitable and increase the supply of clean and dirty capital loans (more so with clean capital loans). This is evident from fig. 3, where both types of loans rise above the steady-state post the initial dip after the shock.

Such an expansion in bank lending is short-lived as costly lending rates cause investment to shrink further. In fact, clean capital and investment shrink more under competitive ϕ_x. The reverse is true for dirty capital and investment as dirty capital loans are relatively cheaper than clean capital loans. Thus, emissions drop by less with a competitive ϕ_x. Thus, giving banks autonomy in setting the emission-elastic lending coefficient can have undesirable environmental consequences depending on the nature of the shock.

The emission-elastic lending rate does not bode well for households in the context of consumption demand shock due to two reasons. First, deposits are more volatile. Second, households face disutility as emissions drop by less. Both the aforementioned factors can likely explain the negative value of the socially optimal ϕ_x under consumption demand shock.

7 Sensitivity analysis

The results from section 5 and section 6 show that banks prefer issuing emission-elastic lending rates due to an increase in bank profit margin. Furthermore, the results show that such lending rates which provide favourable terms for clean capital borrowing may not necessarily improve social welfare. In this section, we investigate the sensitivity of our main results.

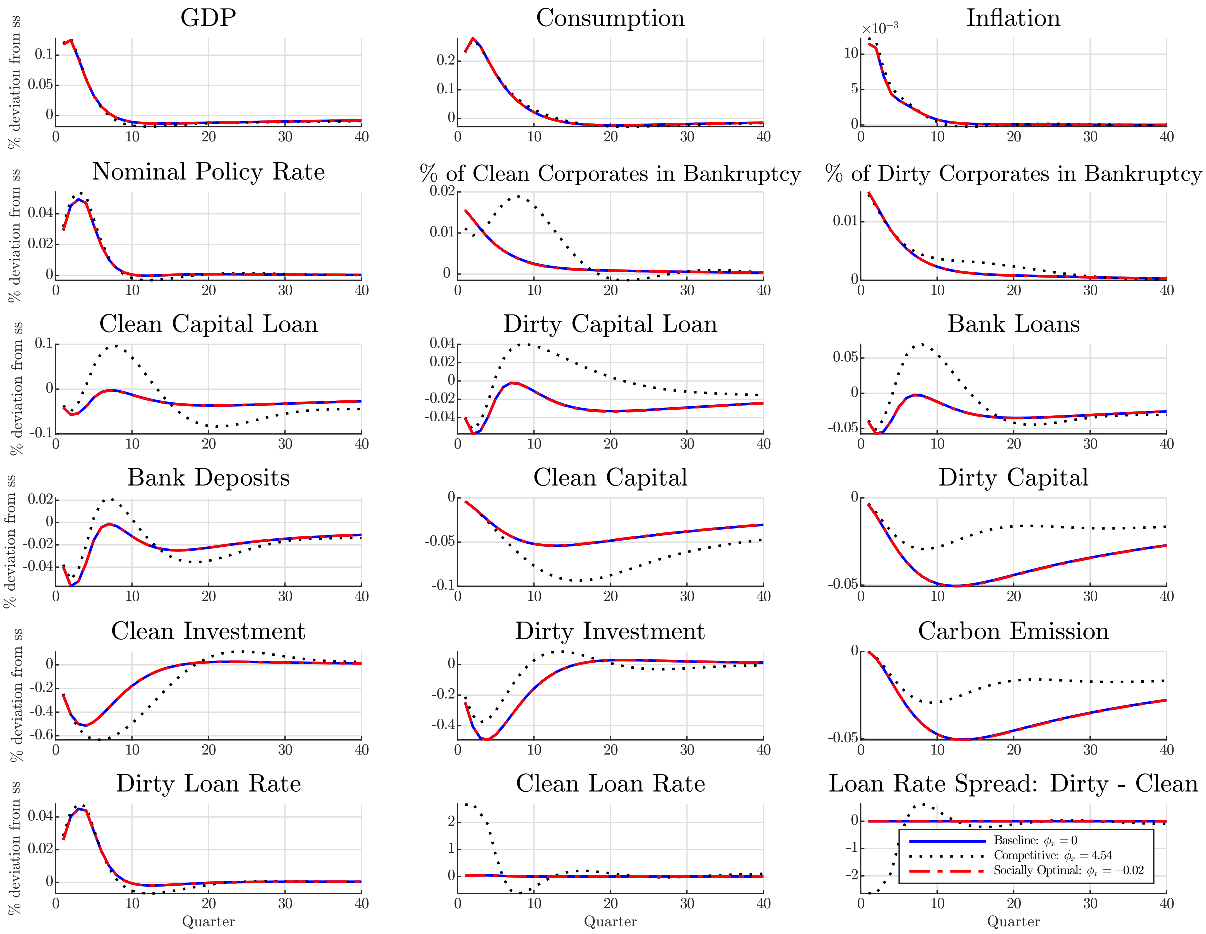

Figure 3: Consumption demand shock

Note: This figure shows the impulse responses of key variables following a positive one standard deviation consumption demand shock.

7.1 Clean capital productive efficiency

The literature on E-DSGE models does not differentiate between the productive efficiency of dirty and clean capital (Punzi, 2018; Carattini et al., 2021; Annicchiarico et al., 2022). Our model adheres to a similar format and assumes A_c in eq. (33) to equal 1. However, such an assumption may not hold well in reality, as limited technological advancement in clean capital would imply that a unit of dirty capital is more productive in generating output than one unit of clean capital (Rozenberg et al., 2014). To address this point, we consider the scenario with $A_c = 0.5$, wherein the productive efficiency of clean capital is smaller than dirty capital. One may also argue that such disparities in productive efficiency may not persist into the future, given the enormous R&D investments pumped into developing clean capital. The future might hold a reality where clean capital is more productive than dirty capital. Hence, we also consider an alternative scenario of $A_c = 1.5$ in our analysis.

Panel A of Table 8 shows the steady-states of clean and dirty capital for A_c equals 0.5, 1, and 1.5. In the baseline scenario ($A_c = 1$), the steady-state values of both capital types are very close. This changes when A_c equal 0.5 as the usage of dirty capital is more than clean capital. In contrast, clean capital usage is more than that of dirty capital when A_c equal 1.5. Thus, the productive efficiency parameter A_c has strong implications on steady-states of clean and dirty capital. Clean capital productive efficiency parameter also has implications on the choices concerning emission-elastic lending rate coefficient ϕ_x. We conduct similar grid searches as in section 5 to find the competitive and socially optimal ϕ_x values for $A_c = 0.5, 1.5$. Panel B of table 8 reports the results along with the baseline ($A_c = 1$) results from section 5.

The value of competitive ϕ_x rises when A_c increases. This is intuitive since an increase in clean capital productive efficiency induces higher demand for clean capital loans when favourable loan terms are provided for clean capital borrowing. When banks satisfy this demand with more loan issuance, profits from lending increase. This is indeed what we see in table 8 where higher intensity in A_c is accompanied by larger profit gain. In contrast, socially optimal ϕ_x declines when A_c increases. This inverse relationship again lies in the deepening of clean capital loan demand with higher A_c. As explained previously in section 6, large movements in clean capital loans increase instability in aggregate loans, which in turn causes more volatile aggregate deposits. Hence, emission-elastic lending rates cause more adversity for households when clean capital productive efficiency intensifies. As a result, socially optimal ϕ_x declines with clean capital productive efficiency improvements.

Table 8: Implications of clean capital productive efficiency

	$A_c = 0.5$	$A_c = 1$	$A_c = 1.5$
Panel A: Steady states			
Clean capital	8.9715	15.5660	20.9230
Dirty capital	15.7429	13.6576	12.2387
Panel B: Emission-elastic lending rate			
Competitive ϕ_x	0.93	1.51	2.09
Profit gain (%)	0.00451	0.01037	0.01598
Socially optimal ϕ_x	0.26	0.25	0.24
Welfare gain (%)	0.00035	0.00042	0.00041

7.2 Emissions disutility

In section 6, we discussed the importance of households' disutility towards emissions as pertinent for socially optimal ϕ_x to be greater than zero. The emission weight parameter in households' utility function, μ_x, is important for emission-elastic lending rates to be associated with social welfare gains, i.e. socially optimal $\phi_x > 0$. To validate the role of the disutility parameter, we conduct grid searches as in section 5 to find the socially optimal ϕ_x when μ_x varies from 0 to 5. Table 9 shows the results both in the context of simultaneous and individual shocks. Both in situations where the economy faces simultaneous shocks and technology shock alone, a positive socially optimal ϕ_x arises only when $\mu_x > 0.1$.[10] In other words, the disutility from emissions that occur with $\mu_x > 0$ is crucial for emission-elastic lending rates to generate welfare improvements (i.e socially

[10]Table 5 shows technology shock to mostly explain the key variables' volatility. Hence, the technology shock dynamics dominate the results from simultaneous shocks.

optimal $\phi_x > 0$). Higher μ_x accompanies larger values of socially optimal ϕ_x. Table 9 also shows that there is an upper threshold at $\mu_x = 2$, beyond which the socially optimal ϕ_x does not increase. In the case of the individual shock to consumption demand, we again see the socially optimal ϕ_x to increase with emission disutility weight. However, it is interesting to note socially optimal ϕ_x does not push beyond 0 for any value of μ_x in the context of consumption demand shock. In other words, for any value of the emission disutility weight, emission-elastic lending rates does not lead to improvements in social welfare (i.e. a positive socially optimal ϕ_x) for consumption demand shock.

Table 9: Socially optimal ϕ_x and emissions dis-utility

μ_x	Socially optimal ϕ_x		
	Simultaneous shocks	Technology shock	Cons. demand shock
0	-0.47	-0.47	-0.46
0.1	-0.11	-0.10	-0.22
0.2	0.03	0.05	-0.14
0.3	0.10	0.13	-0.10
0.4	0.15	0.18	-0.08
0.5	0.18	0.22	-0.06
0.6	0.20	0.24	-0.05
0.7	0.22	0.26	-0.04
0.8	0.23	0.28	-0.03
0.9	0.24	0.29	-0.03
1	0.25	0.30	-0.02
1.1	0.26	0.30	-0.02
1.2	0.26	0.30	-0.02
1.3	0.27	0.30	-0.02
1.4	0.27	0.30	-0.01
1.5	0.28	0.30	-0.01
2	0.29	0.30	0
3	0.30	0.30	0
4	0.30	0.30	0
5	0.30	0.30	0

8 Environmental policy and transition to greener economy: The role of emission-elastic lending rates

In this section, we assess the effect of emission-elastic lending rates in transitioning to a greener economy through an expected permanent increase in carbon tax by 1%. Figure 4 shows the transition dynamics in response to the permanent rise in carbon tax. The solid blue, dashed red, and dotted black lines correspond to emission elastic-lending rate coefficient ϕ_x at 0, 0.1, and 0.5, respectively. The exogenous rise in carbon prices makes dirty capital expensive. Firms' demand less dirty capital, and emissions decline as a result. There is stronger capital reallocation in the absence of emission-elastic lending rates, and as a consequence, the transition risk is higher. When ϕ_x is positive, the dip in emission growth increases clean capital lending rates, thereby causing more clean corporates to be bankrupt. Hence, clean capital does not rise as much with emission-elastic lending rates (see red and black lines). As a consequence, carbon tax-induced capital reallocation is more muted in the context of emission-elastic lending rates, with the transition to a greener economy more gradual. The percent of dirty corporates in bankruptcy becomes less at higher values of ϕ_x. Hence, emission-elastic lending rates can reduce the transition risk. As in Carattini et al. (2021), we find the emission-elastic lending rates to mitigate transition risk arising from carbon tax shock. Although the transition risk is subdued, emission-elastic ending rates are associated larger financial sector distortions. This is evident from the more volatile responses of bank loans and deposits as ϕ_x increases.

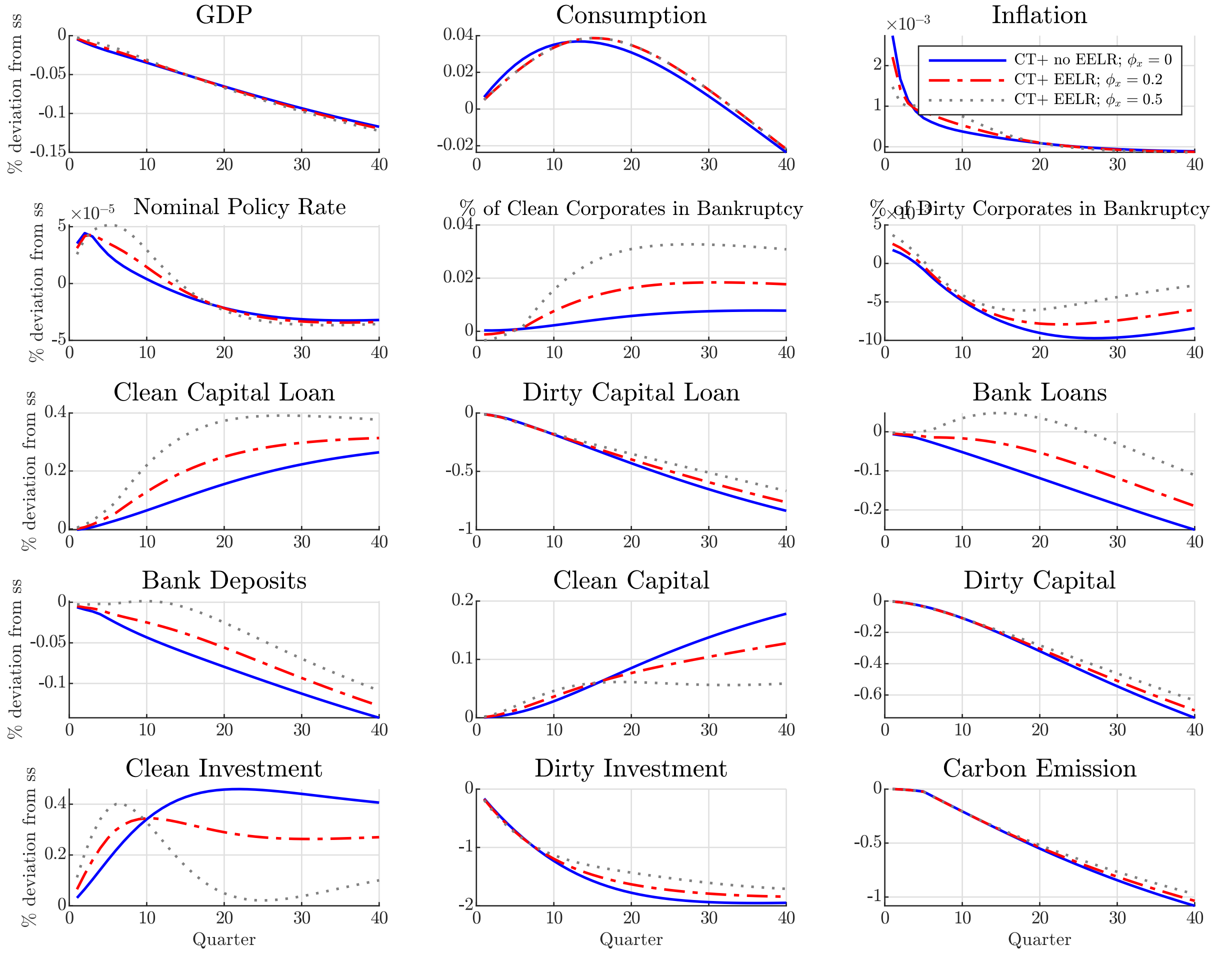

Figure 4: Carbon tax shock with emission-elastic lending rates

Note: This figure shows the transition dynamics following a permanent increase in carbon tax by 1% which was pre-announced by five periods. The blue line pertains to carbon tax policy + no emission-elastic lending rate scenario (CT+ no EELR). The red and black lines pertain to scenarios with carbon tax policy + emission-elastic lending rate (CT + EELR) where ϕ_x equals 0.1 and 0.5, respectively.

9 Conclusion

This paper develops a two-sector New Keynesian DSGE model with a full-fledged banking sector following Benes & Kumhof (2015) where capital investment funds borrow from banks to finance capital purchases. Commercial banks differentiate lending rates between clean and dirty capital investment funds using emission-elastic lending rates. When emission growth exceeds the target, banks lower the lending rates to clean capital investment funds, resulting in a lower cost of clean capital. As a consequence, firms substitute dirty capital inputs with clean capital inputs, resulting in emission reduction.

This paper evaluates the consequences of emission-elastic lending rates beyond emission abatement. We find that emission-elastic lending rates can spur the demand for loans resulting in an aggregate lending expansion, thereby increasing bank profit margins. However, the significant changes in lending associated with emission-elastic lending rates increase financial sector uncertainty, adversely affecting social welfare. Finally, we also find that emission-elastic lending rates can dampen transition risk when the economy faces a permanent increase in carbon tax with more subdued capital reallocation between clean and dirty sectors. However, financial sector uncertainty increases when emission-elastic lending rates interacts with the carbon tax shock.

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Online Appendix

A FOC for banks' optimization problem

First we define a uxiliary variable:

$$\sqcap_t = \frac{\chi \mathfrak{f}_t^b(\bar{\omega}_{t+1}^b)\left(\frac{l_{dt}+l_{ct}}{\mathsf{n}_t^b}\right)}{\left((1-\gamma_t)\frac{r_{dt+1}^l l_{dt}+r_{ct+1}^l l_{ct}}{\mathsf{n}_t^b}\right)^2}$$

The first order condition (FOC) w.r.t. dirty loan l_{dt}:

$$0 = \mathbb{E}_t\Bigg\{ r_{dt+1}^l - r_{d,t+1} - \chi \mathfrak{F}_t^b(\bar{\omega}_{t+1}^b) - \sqcap_t \times$$
$$\left[r_{d,t+1} r_{dt+1}^l (1-\gamma_t) + r_{cl,t+1} \frac{l_{ct}}{\mathsf{n}_t^b}(1-\gamma_t)(r_{ct+1}^l - r_{dt+1}^l) \right] \Bigg\}$$

The first order condition (FOC) w.r.t. clean loan l_{ct}:

$$0 = \mathbb{E}_t\Bigg\{ r_{ct+1}^l - r_{d,t+1} - \chi \mathfrak{F}_t^b(\bar{\omega}_{t+1}^b) - \sqcap_t \times$$
$$\left[r_{d,t+1} r_{ct+1}^l (1-\gamma_t) + r_{dl,t+1} \frac{l_{dt}}{\mathsf{n}_t^b}(1-\gamma_t)(r_{dt+1}^l - r_{ct+1}^l) \right] \Bigg\}$$

B Elasticity of substitution between goods

It is natural to question whether lowering the elasticity of substitution between goods ($\epsilon = 6$) from our baseline results would alter the effects of emission-elastic lending rates on social welfare and profits, by making it more difficult for the economy to substitute dirty inputs for green ones. We can thus examine this issue and provide more compelling justifications for their calibration selection.

Following the literature such as Hart (2019) and Greaker et al. (2018), we consider three cases of substitution between goods for our sensitivity analysis, namely 4, 3, and 1.5. In table 10, we present the results. As shown, the positive welfare gains from the lending spread could vanish if ϵ is sufficiently small.

However, the impact on bank profits differs. Bank profit margin increases when a lower elasticity of substitution. In summary, decreasing the elasticity of substitution between goods could quantitatively affect our results, but the main conclusions still hold.

Table 10: Sensitivity analysis of elasticity of substitution between goods

	$\epsilon = 4$	$\epsilon = 3$	$\epsilon = 1.5$
Competitive ϕ_x	2.09	2.67	4.16
Profit gain (%)	0.01701	0.02425	0.04399
Socially optimal ϕ_x	0.2	0.13	0.06
Welfare gain (%)	0.00025	0.00010	0.00002

C Sensitivity analysis with different ϕ_1

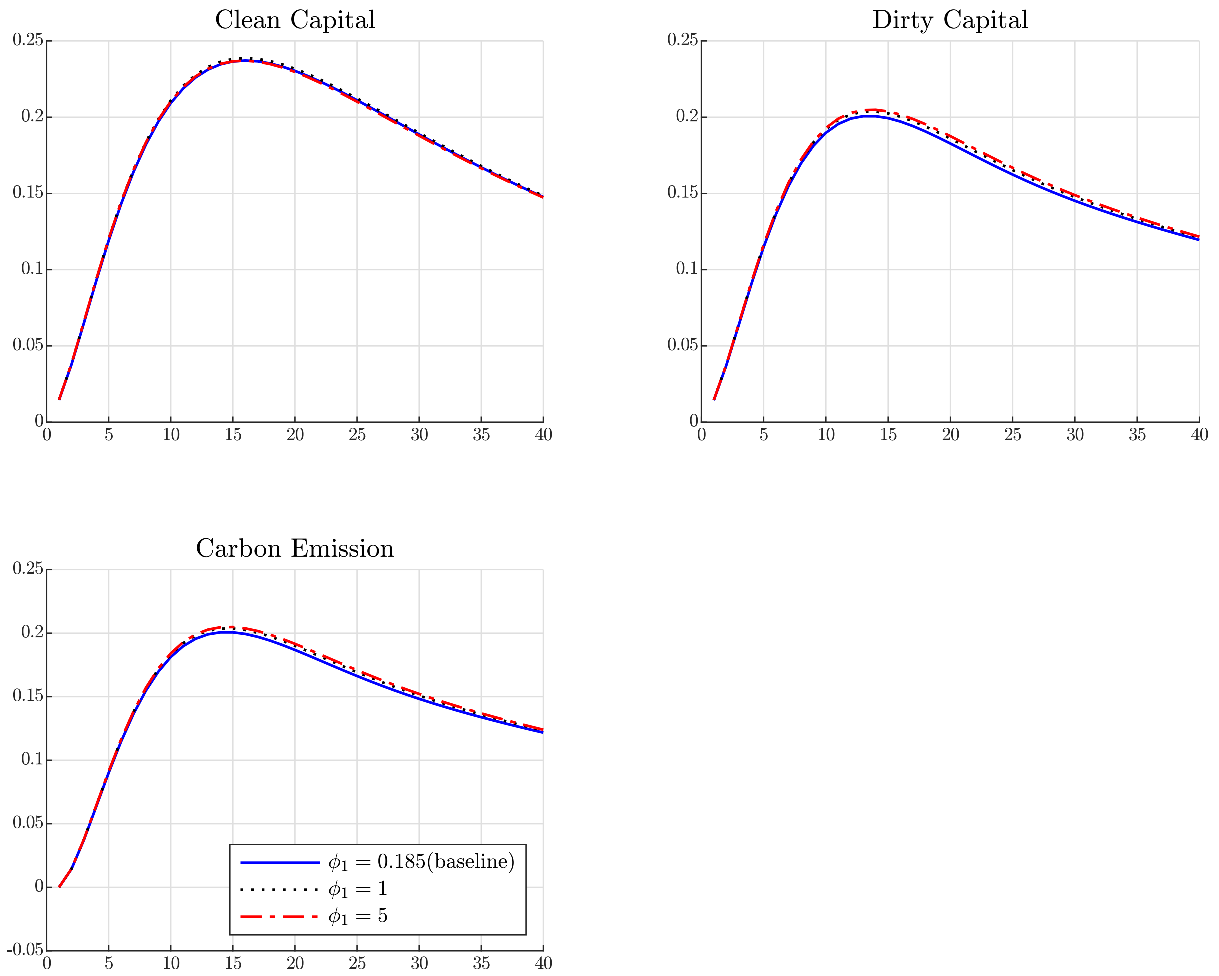

Figure 5: Sensitivity analysis with different ϕ_1

Note: This figure shows the impulse responses of key variables following a positive one standard deviation technology shock with different ϕ_1.

D Other figures in welfare analysis

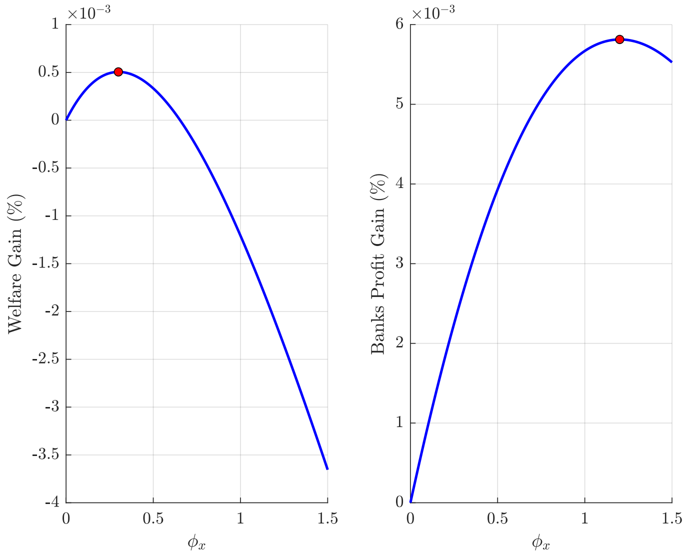

Figure 6: Welfare and banks pre-dividend analysis for supply shock

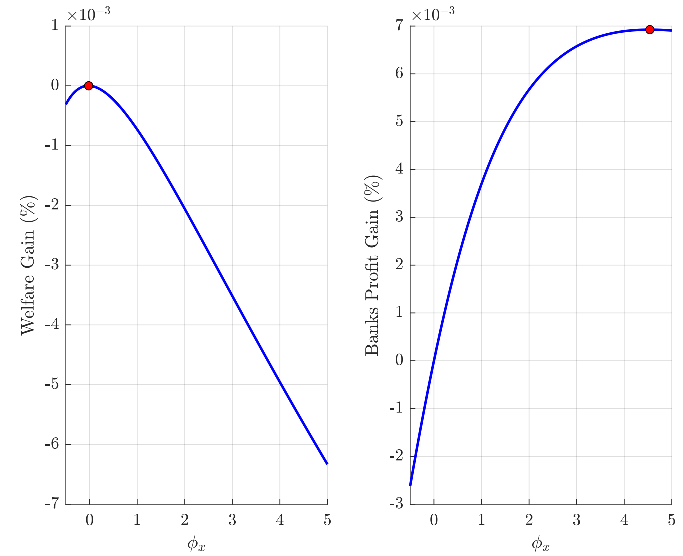

Figure 7: Welfare and banks pre-dividend analysis for demand shock