Emission-elastic Lending Rate: Implications on Environment, Welfare, and Financial Stability

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]Department of Economics, National University of Singapore

[*]Corresponding author: heniexka@gmail.com

September 15, 2022

Abstract

Differentiated terms for clean and dirty capital loans have become a popular tool among commercial banks as they promote themselves as advocates of environmental sustainability. The question remains whether such initiatives by the commercial banks are consistent with the welfare objective of the social planner. We develop a two-sector New Keynesian Dynamic Stochastic General Equilibrium (DSGE) model in which banks impose an emission-elastic lending rate for clean capital loans, and examine the welfare implications of the banks' profit-maximizing premium. Calibrating the model to the US economy, we find that a) the emission-elastic rate can improve both bank profits and social welfare; b) emission-elastic lending rates accompany banking sector instability; and c) an improvement in social welfare with emission-elastic lending rates can be realized only when agents sufficiently "care" about the negative externality from emissions. Additionally, emission-elastic lending rate can substitute for a carbon tax in moving the firms toward cleaner production smoothly.

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]

The recent decade has witnessed a proliferation of initiatives among the financial institutions to promote environmental sustainability. Banks, being an important source of funds in firms' production processes, appear to play a role in directing financing towards cleaner production and carbon emission abatement (De Gouvello & Zelenko (2010)). Historically, creditworthiness in repaying loans was among the key deciding factors for banks to issue loans to corporates. The deciding factors have now expanded to include the environmental friendliness of the corporates. Typically, production sector's decision concerning environmentally friendly input choices is contingent on the availability of funds to finance clean investments. Initiatives among banks to promote environmental sustainability include provision of differentiated lending rates for corporates with different ratings of environmental friendliness. For instance, the People's Bank of China has launched a carbon emission reduction facility to offer low interest loans to financial institutions which help firms aiming to reduce carbon emissions.[3]

In partial equilibrium, such differentiated lending rates create an incentive for investment funds to direct the financing towards inputs that reduce negative environmental impact in production. A corporate showing a tendency to generate positive environmental impact is entitled a preferential rate for the loans it borrows from the banks. To continue enjoying this preferential rate, the corporate keeps a track record of its positive environmental impact. On the other hand, a corporate that has generated negative impact on the environment is penalised with a higher borrowing cost. The coporates have to finance clean production inputs to benefit from a lower cost of borrowing.

Questions arise as one considers all economic interactions. First, what are the motives behind banks' differentiated lending rates? When cleaner investment funds obtain loans with preferential rates, the increase in the loan volume ought to offset the lower unit interest income. Only then, the differentiated interest rates are consistent with banks' profit-maximizing objective. Otherwise, if the lower interest rate implies a loss to the banks due to lower interest income, banks' net worth may shrink, leading to insolvency.

[1] Available at the International Monetary Fund (IMF) Blog.
[2] Available at the World Bank Blog.
[3] The details can be found at https://greencentralbanking.com/2021/11/10/pboc-launches-targeted-green-lending/.

Second, are the banks doing what the social planner wants to do? The social planner, usually the environmental agency, introduces policies that correct the externalities arising from economic activity. It aims to find a compromise among all economic agents' welfare. The banks, being one of the economic agents, may only have the incentive to maximize their own profits. It is important to identify any misalignment between the objectives of the social planner and the banks, so that appropriate correction measures can be implemented, and Pareto improvements can be achieved.

We address the above two questions in this paper through a DSGE framework. Our key contribution lies in detailing commercial banks' optimizing behaviour as they introduce differentiated interest rates to promote environmental sustainability. The optimizing processes among the banks is important because they pertains to the stability not only within the financial system, but also the overall economy. Existing literature has briefly covered the role of financial sector in greening the economy, but none has considered a full-fledged banking sector. We model banks as liquidity-generating houses in the economy, similar to how banks work in reality as in Javadi & Masum (2021). We also consider the financial risks faced by the banks when they issue loans to borrowers. With these details, it is easy for us to analyse the economic welfare dynamics due to varying liquidity conditions.

Our analyses rely on counterfactual simulations from a two-sector DSGE model. The reference model is from Benes & Kumhof (2015) and Barrdear & Kumhof (2021) who developed a model for risky lending among the banks. We extend the model to consider both clean and dirty capital investments. We introduce a lending rate that changes with the extent of carbon emission, so that clean capital investment funds that help firms to achieve lower carbon emissions are entitled a lower interest rate for their loans. We name this interest rate an *emission-elastic lending rate*. Our analyses revolve around finding the optimal response of this interest rate towards carbon emissions from the perspectives of the banks and the social planner.

We summarize the main findings of the paper in three points. First, the emission-elastic rate can improve both bank profits and social welfare. The surge in clean capital loan demand stemming from favourable loan terms increases bank profits. The subsequent re-allocation in financing enables the manufacturing firm to adopt more clean capital in the production process. Thus, emission-elastic lending rates help control emissions, thereby improving social welfare. Second, emission-elastic lending rates accompany banking sector instability. Bank loans and deposits are more volatile when emission-elastic lending rates are issued. Third, an improvement in social welfare with emission-elastic lending rates can be realized only when households "care" about the negative externality from emissions. The instability of the banking sector associated with emission-elastic lending rates adversely affects the households since they prefer stable saving patterns. On the other hand, better emission management benefits the household (only if the agents suffer disutility from emissions). Hence, agents should have sufficient disutility towards emissions for emission-elastic lending to improve social welfare. Additionally, we find that an emission-elastic lending rate can substitute for a carbon tax in moving the firms toward cleaner production.

Related Literature This paper is related to several branches of literature. Our paper is related to the rapidly growing literature using the environmental DSGE (E-DSGE) model to study business cycles and the green policy (see e.g. 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. (2021) and Pan (2019)).[4] Angelopoulos et al. (2013) and Fischer & Heutel (2013) are early contributions in the literature on the environment policy and business cycles. They use the real business cycle (RBC) model to address the environmental issues and design policies to tackle carbon emissions. Recently, there are several extensions along this line of research. Dissou & Karnizova (2016) construct a multi-sector model to investigate 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 on directing investment towards the clean environment.

Our paper is also related to papers studying the financial transition risk as the economy transits towards cleaner production (see e.g. Campiglio et al. (2018), de France (2019), Carney (2015), Ferrari & Nispi Landi (2021), Punzi (2018), and 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 the 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 there is an imperfect substitutability between green and brown bonds. Benmir & Roman (2020) and Diluiso et al. (2021) echo similar findings. Our paper differs from the previous studies by considering differentiated lending rates as an instrument and examine its implications on financial stability.

In addition, we are close to another strand of literature on the intersection of the macroeconomic policy and the environment policy. For example, Economides & Xepapadeas (2018) employ a E-DSGE model to study the role of monetary policy under climate change and show that climate change does affect the design of monetary policy. Diluiso et al. (2021) also use a 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.

Finally, we are closely related to the concurrent papers of Carattini et al. (2021) and Diluiso et al. (2021) who study a financial transition problem using E-DSGE model with banking sectors. However, our discussion differs from theirs in the following ways. First, their work is mainly based on Gertler & Kiyotaki (2010) and Gertler & Karadi (2011) where banks are holders of risky equity, while this paper

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

follows Benes & Kumhof (2015) and Barrdear & Kumhof (2021) lines of works and develops a E-DSGE model with financial frictions assuming that banks are lenders. The equity feature of Gertler & Karadi (2011) is subject to price risks but our model can stress the credit risks of bank loans as in Benes & Kumhof (2015). This important difference between the two settings can help us to clear up the effects of credit risks of loans on the environment, welfare, and financial stability.

Second, their works mainly focus on the *exogenous* policy shocks such as the QE policy, the carbon tax policy or the macro-prudential policy. However, In this paper, we instead explore the *endogenous* environment policy on capitals which is contingent on carbon emission. In other words, we propose a policy to require banks to charge different loan rates on clean and dirty capital to enhance green production termed as emission-elastic lending spread. This idea is in line with Javadi & Masum (2021) who empirically show that firms with higher exposure to climate change pay significantly higher spreads on bank loans. Additionally, we compare this measure with the traditional carbon tax policy as in Annicchiarico & Diluiso (2019) and Carattini et al. (2021). To the best of our knowledge, the rule to require banks to impose an carbon emission-elastic lending rate for clean capital loans is missing in the literature and the quantitative examination on the environment, welfare, and financial risks under the loan rate spread is also in infancy. We are the first paper to fill this gap to discuss the effects of (endogenous) loan rates spread. Third, contrary to these two works, this paper follows Acemoglu et al. (2012) to investigate the implications of carbon emission on households' welfare by directly incorporating a component that captures the effect of carbon emission into the household's utility function.

Organization This paper proceeds as follows. Section 2 shows the two-sector E-DSGE model in which banks impose an emission-elastic lending rate premium for clean capital loans. Section 3 elaborates the model parameterisation. Section 4 presents analyses on social welfare and bank profit with emission-elastic lending rates. Section 5 shows the dynamic responses following technology and consumption demand shock. Section 6 shows sensitivity of the main results to clean capital productive efficiency and emission disutility. Section 7 shows emission-elastic lending rates as an alernative mechanism to carbon tax. Finally, section 8 concludes.

2 Model

Our model constitutes a full fledged banking sector who lends to capital investments agencies for financing capital purchase. We extend the bank lending framework in Benes & Kumhof (2015) to include clean and dirty capital investment agencies. The presence of the emission-elastic lending rates helps banks to provide differentiated lending rates between clean and dirty capital purchases. Firms rent capital from both types of capital investment agencies and use them as inputs in production (George et al., 2021). 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 denotes clean and dirty, respectively. Capital goods firms sell capital stock to capital investment agencies at competitive prices. Final goods firm 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 ϖ^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:

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

In period $t+1$, only proportion $\left[1 - \mathfrak{F}^k_t(\varpi^k_{jt+1})\right]$ 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:

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

where the whole-sale 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 $G_{jt+1} = \int_0^{\varpi^k_{jt+1}} \omega^k_{jt+1}\mathfrak{f}^k_t(\omega^k_{jt+1})d\omega^k_{jt+1}$. $\Gamma_{jt+1} \equiv \int_0^{\varpi^k_{jt+1}} \omega^k_{jt+1}\mathfrak{f}^k_t(\omega^k_{jt+1})d\omega^k_{jt+1} + \varpi^k_{jt+1}\int_{\varpi^k_{jt+1}}^{\infty} \mathfrak{f}^k_t(\omega^k_{jt+1})d\omega^k_{jt+1}$ 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:

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

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]

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

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

Emission-elastic lending rate Banks provide low cost funding to clean capital investment agencies through an emission-elastic lending rate. On the other hand, dirty capital investment agencies does not enjoy similar loan privileges. 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 the domestic carbon emission and $\phi_x>0$ implies that clean capital investments agencies are offered a lending rate lower than the market determined rate i^l_{ct} when emissions increase. In this case, a positive ϕ_x creates a spread between the dirty and clean capital lending rates. The market distortion from emission-elastic lending spread causes asymmetric effects on the loan demand from clean and dirty capital investment agencies. Lower borrowing costs can encourage clean capital investments agents to finance more clean capital. In short, emission-elastic spread endogenously encourages clean capital when emissions are high.

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 $k_t(i)=[\upsilon^{1/\varphi}k_{dt}(i)^{1-1/\varphi}+(1-\upsilon)^{1/\varphi}(A_ck_{dt}(i))^{1-1/\varphi}]^{\frac{\varphi}{\varphi-1}}$ 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. $\Lambda\left(m_t\right)$ is the damage function of global carbon emission stock m_t which takes the functional form:

$$\Lambda\left(m_t\right)=\gamma_0+\gamma_1m_t+\gamma_2m_t^2. \tag{32}$$

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

$$x_t(i)=\left[1-\vartheta_t(i)\right]\phi_dk_{dt-1}(i), \tag{33}$$

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

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:

$$\Pi_t^m(i) = \max_{n_t(i),k_{dt}(i),k_{ct}(i),\vartheta_t(i)} y_t(i) - w_t n_t(i) - r_{dt}^k k_{dt-1}(i) - r_{ct}^k k_{ct-1}(i) - \tau_t^x x_t(i) - \mathcal{C}_t^A(i), \tag{34}$$

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

$$\mathcal{C}_t^A(i) = \phi_1 \vartheta_t(i)^{\phi_2} k_{dt-1}(i) \tag{35}$$

Final goods firm maximizes eq. (34) subject to eqs. (31), (33) and (35). The resulting first-order conditions are:

$$n_t(i) : (1-\alpha)\frac{y_t(i)}{n_t(i)} = \frac{w_t}{mc_t(i)}, \tag{36}$$

$$k_{ct-1}(i) : \alpha\,(1-\upsilon)^{1/\varphi}\frac{y_t(i)}{k_{ct-1}(i)}\left(\frac{k_{ct-1}(i)}{k_{jt-1}(i)}\right)^{-1/\varphi} = \frac{r_{ct}^k}{mc_t(i)}, \tag{37}$$

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

$$\vartheta_t(i) : \tau_t^x \phi_d = \phi_1 \phi_2 \vartheta_t(i)^{\phi_2 - 1}, \tag{39}$$

where $mc_t(i)$ is the firm's marginal cost and $\tilde{r}_{dt}^k(i) = r_{dt}^k + \tau_t^x \phi_d\,[1-\vartheta_t(i)] + \phi_1\vartheta_t(i)^{\phi_2}$ is the abatement cost adjusted rent accrued to dirty capital. The adjusted rental costs on dirty capital ensures firms to internalise environment externality. eq. (39) 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:

$$\tilde{\pi}_t = \frac{\epsilon}{\epsilon - 1}\frac{\sum_{h=0}^{\infty}\theta^h \mathbb{E}_t \mathcal{Q}_{t,t+h}\left(\frac{p_t}{p_{t+h}}\right)^{-\epsilon} y_{t+h} mc_{t+h|t}}{\sum_{h=0}^{\infty}\theta^h \mathbb{E}_t Q_{t,t+h}\left(\frac{p_t}{p_{t+h}}\right)^{1-\epsilon} y_{t+h}}, \tag{40}$$

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:

$$1 = \theta \pi_t^{\epsilon - 1} + (1-\theta)\tilde{\pi}_t^{1-\epsilon}. \tag{41}$$

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:

$$\tau_t^{ls} + \tau_t^x x_t + \mathcal{T}_t^b = g_t. \tag{42}$$

$\mathcal{T}_t^b = \chi l_t \mathfrak{F}_t^b(\varpi_{t+1}^b)$ 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:

$$i_t = (i_{t-1})^{\rho_i} \left[\frac{1}{\beta} \left(\frac{\pi_t \pi_{t+1} \pi_{t+2} \pi_{t+3}}{\pi^4} \right)^{\phi_\pi} \left(\frac{y_t}{\bar{y}} \right)^{\phi_y} \right]^{1-\rho_i}, \tag{43}$$

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:

$$\gamma_t = \bar{\gamma} \left(\frac{l_t}{\bar{l}} \right)^{\phi_l}, \tag{44}$$

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:

$$y_t = c_t + g_t + \mathcal{C}_t^A + \sum_{j \in \{c,d\}} I_{jt} \left[1 + \frac{\phi_I}{2} \left(\frac{I_{jt}}{I_{jt-1}} - 1 \right)^2 \right]. \tag{45}$$

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

$$s_t y_t = A_t \left[1 - \Lambda(m_t) \right] n_t^{1-\alpha} k_{t-1}^{\alpha}, \tag{46}$$

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:

$$s_t = (1-\theta) \tilde{\pi}_t^{-\epsilon} + \theta \pi_t{}^\epsilon s_{t-1}. \tag{47}$$

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:

$$\ln(\mathbf{e}_t) = \rho_{\mathbf{e}} \ln(\mathbf{e}_t) + (1-\rho_{\mathbf{e}}) \ln(\bar{\mathbf{e}}) + \varepsilon_{\mathbf{e}}, \quad \varepsilon_{\mathbf{e}} \sim N(0, \sigma_{\mathbf{e}}^2) \tag{48}$$

3 Parameterization

We calibrate our model using parameter values from past literature. 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. (2021), 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 between goods 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 utility function are in line with Benes & Kumhof (2015). The functional form of carbon emission in households 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 6. 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. (2021); Punzi (2018). The abatement cost parameters (ϕ_1 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. (2021) 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 carbon tax is 21.66%, which is in line with George et al. (2021). 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 of clean capital in 6.

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.[6]. 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

[6]The data are achieved from FRED database. The proxy variable for risk free rate (policy rate) is 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 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

Table 3: Standard deviation and autocorrelation

	Standard deviation		Autocorrelation	
	Data	Model	Data	Model
GDP	2.15	1.87	0.32	0.49
Consumption	2.19	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

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 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

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

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

$$\mathcal{W}_t = \mathbb{E}_t \sum_{j=0}^{\infty} \beta^t u(c_{t+j}, n_{t+j}, \mathsf{d}_{t+j}, x_{t+j}). \tag{49}$$

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 premium improves 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 premium, 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 $100 \times (V_{\phi_x=optimal} - V_{\phi_x=0})/V_{\phi_x=0}$, $V \in$ {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. When the commercial banks are given autonomy to set the emission-elastic coefficient ϕ_x, a positive value of 1.51 is chosen, indicating an increase of banks' profits when differentiated interest rates are introduced to the financial market. Indeed, our simulation shows that banks' profits rise by about 0.01%. By contrast, the social welfare of the economy decreases by 0.0051% compared to the baseline scenario when ϕ_x is set to be 0. 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.

When the emission-elastic coefficient is chosen by the social planner, both commercial banks' profits and social welfare increase, as shown by the second row in Table 6. Compared to the first case when commercial banks choose the emission-elastic coefficient, the social optimal level of ϕ_x is much smaller in magnitude, about one sixth of the former. This smaller emission-elastic coefficient results in smaller profit gains for commercial banks, implying a potential positive relationship between ϕ_x and banks' profits. To further investigate the relationship between both commercial banks' profits and social welfare and the emission-elastic coefficient, we simulate the full dynamics of social welfare an banks' profits in response to the change in ϕ_x.

The simulation results for social welfare and banks' profits are shown by the left and right panel in fig. 1 respectively. Both display nonlinear relationships between the variable of interest and ϕ_x. Note that welfare and bank profits rise with ϕ_x initially and falls after ϕ_x reaches the value that maximize banks' profits and social welfare respectively. Interestingly, a rise in ϕ_x causes only marginal improvements in social welfare (the left panel). In fact, the household suffers a welfare loss beyond $\phi_x = 0.54$. This is contrary to banks who face sizeable profit gains when ϕ_x increases. Thus, although welfare improves, emission-elastic lending rate creates a trade-off between social welfare and banks' prerogatives to maximize profit.

Individual shocks Table 6 shows a gap between 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 a 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

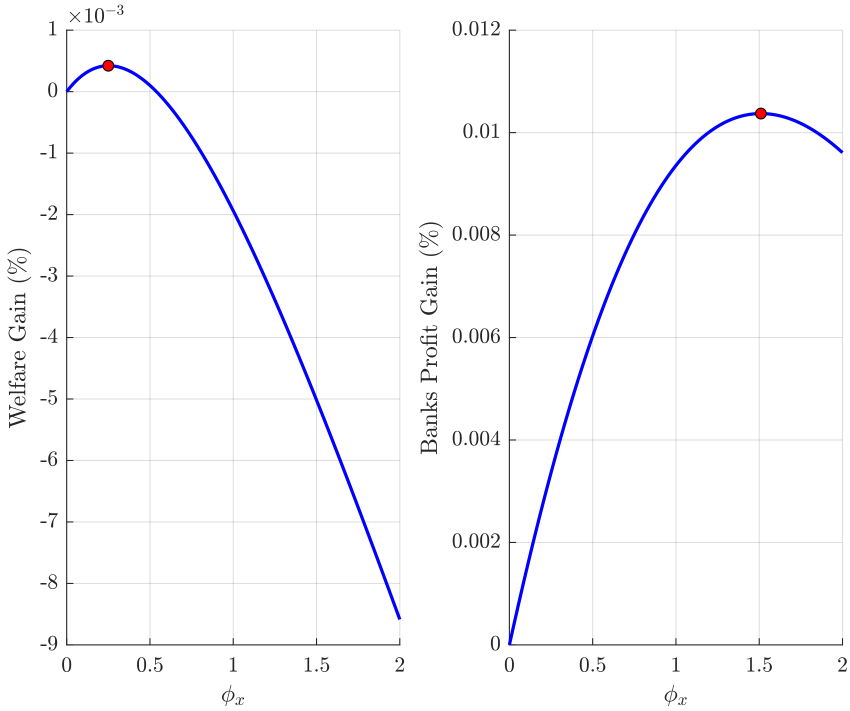

Figure 1: Dynamic plot of welfare gain and bank profit gain

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.[7] 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 results in table 6. This is intuitive given the fact that technology shock largely explains 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 gain in bank profits. section 5 elaborates more on the mechanics that drive the differences between the individual shocks with regard to the emission-elastic lending coefficients and the accompanying bank profits and social welfare.

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

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

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.

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 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) and the share of capital investment agencies (both clean and dirty) in bankruptcy decline. Furthermore, the dip in interest rates induce 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 creates 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. The high degree of competitive ϕ_x can be attributed to the surge in bank profits stemming from the strong clean capital loan demand. 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, higher 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 the dirty capital. A similar dynamic occurs among the investment types as well. Consequently, carbon emissions rise by less.

Although environmentally feasible, emission-elastic lending rates do not elicit financial stability. With emission-elastic leading rates (positive ϕ_x), clean capital loan volatility makes aggregate bank lending more volatile. As a result, bank deposits are also more unstable, as in the case of bank loans through financing through money creation channel. With deposits-in-utility function, volatility in deposits creates duress for the households. In other words, household adversity from deposit volatility cause the social planner to opt for a smaller ϕ_x. Hence, the socially optimal ϕ_x is less than the competitive ϕ_x.

As described previously in section 4, the small yet positive socially optimal ϕ_x implies that social welfare improves with the issuance of emission-elastic lending rate. Then, a natural question would be why such welfare improvements arise when deposit instability increases with ϕ_x. The likely explanation lies in households' disutility towards emissions. A positive ϕ_x helps to reduce emissions which improves social welfare. The benefit from smaller emission growth outweighs the costs of higher deposit volatility, causing the social planner to opt for a small yet positive ϕ_x.

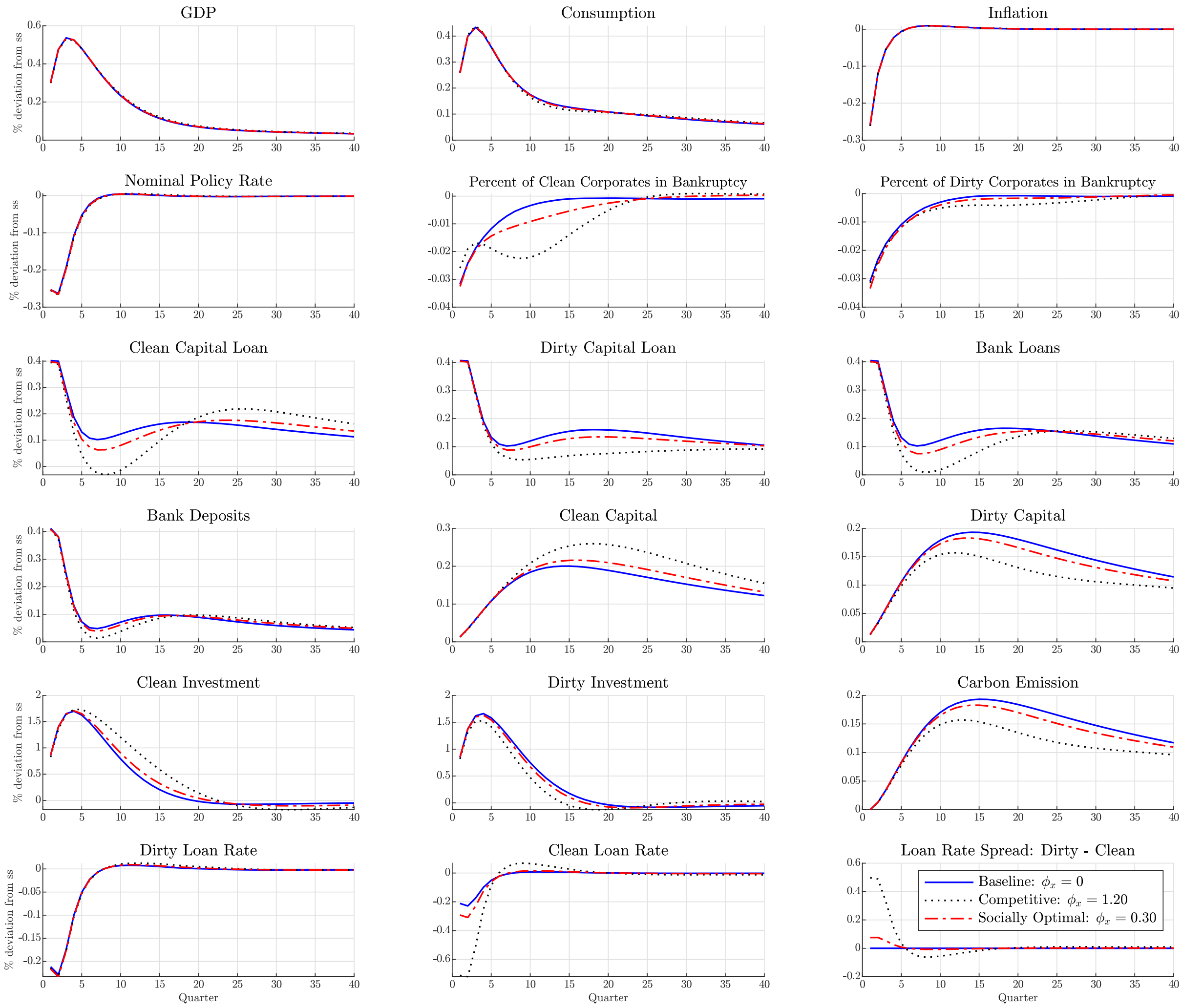

Figure 2: Technology shock

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

Consumption demand shock Figure 3 shows the impulse responses following a positive one standard deviation expansionary consumption demand shock. In the baseline regime, the increase in aggregate demand following an exogenous rise in consumption demand leads to inflation. GDP expands with the consumption increase. Nominal interest rate rises in response to inflation. The consumption rise coupled with high interest rate 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.

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 the lending rates. This changes in the context of emission-elastic lending rates as competitive ϕ_x, which is greater than zero, lead to a narrow spread between dirty and clean capital lending rates. 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, the competitive ϕ_x leads to clean investment and capital shrinking even further than the baseline regime. The reverse is true for dirty capital and investment on account of the relatively inexpensive dirty 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 the households as a) deposits are more volatile and, b) more disutility from a smaller emission drop. Both the aforementioned factors can likely explain the negative value of the socially optimal ϕ_x. The negative ϕ_x implies that the clean lending rate rise by less than the dirty lending rate, resulting in a positive loan spread. Thus with a socially optimal ϕ_x, cheaper clean capital lending rates cause clean capital to drop by less than that of dirty capital. As a result, the drop in emission is larger with socially optimal ϕ_x than baseline and competitive ϕ_x.

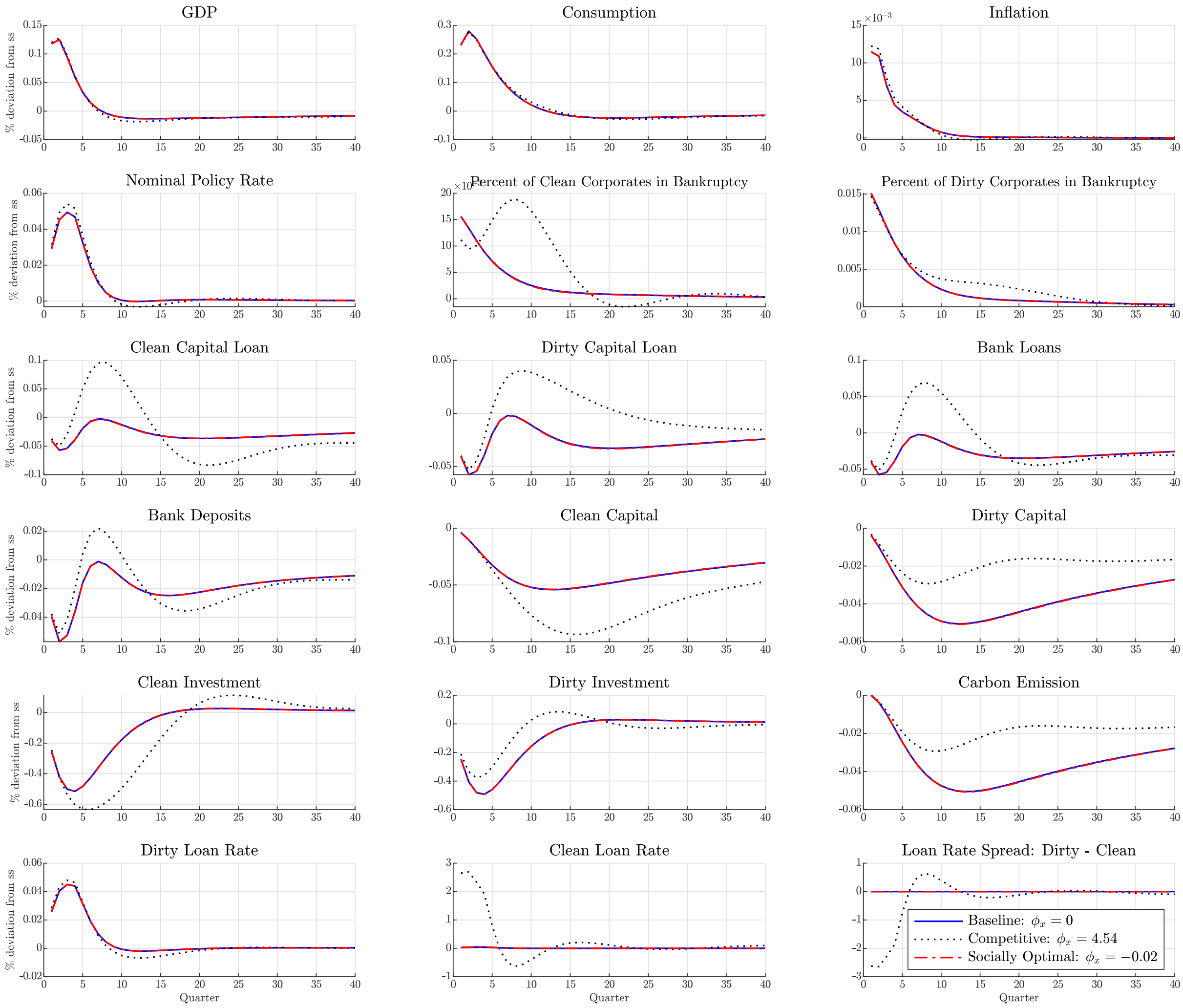

Figure 3: Consumption demand shock

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

6 Sensitivity analysis

The results from section 4 and section 5 show that banks prefer the issuance of 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 to the productive efficiency of clean capital and the households' disutility towards emissions.

6.1 Clean capital productive efficiency

The literature on E-DSGE models do 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 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 for 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 steady-state share of clean and dirty capital in production is dependent on the productive efficiency parameter A_c. 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 4 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 4.

The value of competitive ϕ_x rises when A_c increase. 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 curb 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 decline when A_c increase. This inverse relationship again lies in the deepening of clean capital loan demand with higher A_c. As explained previously in section 5, 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 decline with clean capital productive efficiency improvements. The increase in welfare gain with socially optimal ϕ_x also tapers off as A_c increases.

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

6.2 Emissions disutility

In section 5, we discussed the importance of households' disutility towards emissions as pertinent for society's preference for emission-elastic lending rates, especially in the context of technology shock. In our model, emission disutility is determined by the emission weight parameter in households' utility function, μ_x. Hence, μ_x plays an important role in determining whether households prefer banks to issue emission-elastic lending rates, i.e. positive ϕ_x. To validate the role of the disutility parameter, we conduct grid searches as in section 4 to find the socially optimal ϕ_x while varying μ_x. Table 9 shows that a positive socially optimal ϕ_x arise only when $\mu_x > 0.1$ both in situations where the economy faces simultaneous shocks and technology shock alone.[8] In other words, the negative externality from emissions is crucial for emission-elastic lending rates to generate welfare improvements (socially optimal $\phi_x > 0$). Higher μ_x accompany 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 that the adverse effects of the emission-elastic lending rate result in socially optimal ϕ_x not pushing further than 0 beyond a μ_x threshold. 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]Table 5 shows technology shock to mostly explain the volatility of the key variables. Hence, the results from simultaneous shocks is dominated by the technology shock dynamics.

7 Towards cleaner production: Emission-elastic lending rates as a substitute for carbon tax

The rising literature on E-DSGE models notes carbon tax as an effective policy tool to force firms to move towards cleaner modes of production (see Annicchiarico et al. (2021) for a review). The results in section 5 shows the emission-elastic lending rates as effective in controlling emissions when the economy faces a productivity shock. This section investigates whether emission-elastic lending rates can prove as a alternate channel to carbon tax in moving the economy towards cleaner production.

To perform the comparison between carbon tax and emission-elastic lending rates, we simulate a positive deterministic shock to productivity (technology shock). We assume the intervention of the environmental regulators to control emissions through a deterministic carbon tax shock, that happens five quarters after the shock to productivity. The solid blue line in fig. 4 shows the economy's responses following the positive carbon tax shock. In contrast, the other lines in fig. 4 show the economy's responses that are devoid of the carbon tax shock. Instead, the remaining lines present the responses with emission-elastic lending rates with varying values of ϕ_x.

Although the deterministic carbon tax shock alters the equilibrium path of the carbon emission response in the fifth quarter, emission-elastic lending rates prove better in limiting emissions for a sufficiently high value of ϕ_x i.e. $\phi_x = 1$. This is due to the stronger re-allocation of investments to clean capital from dirty capital with emission-elastic lending rates. Hence, intervention in the loan market to distort clean and dirty capital borrowing decisions helps in stronger substitution to clean capital in comparison to a direct increase in price of emissions (carbon tax). That said, such a result arises only when emission-elastic lending rate coefficient is sufficiently positive. As described in section 5, a strong ϕ_x may not be socially optimal as households face an increase in deposit volatility when ϕ_x increases. This is evident from fig. 4 when bank loans and deposits responses are more volatile with emission-elastic lending rates than with a deterministic carbon tax shock.[9]

[9]We find such financial instability implications to be marginal when emission-elastic lending rates is enforced together with carbon tax shock (see appendix C).

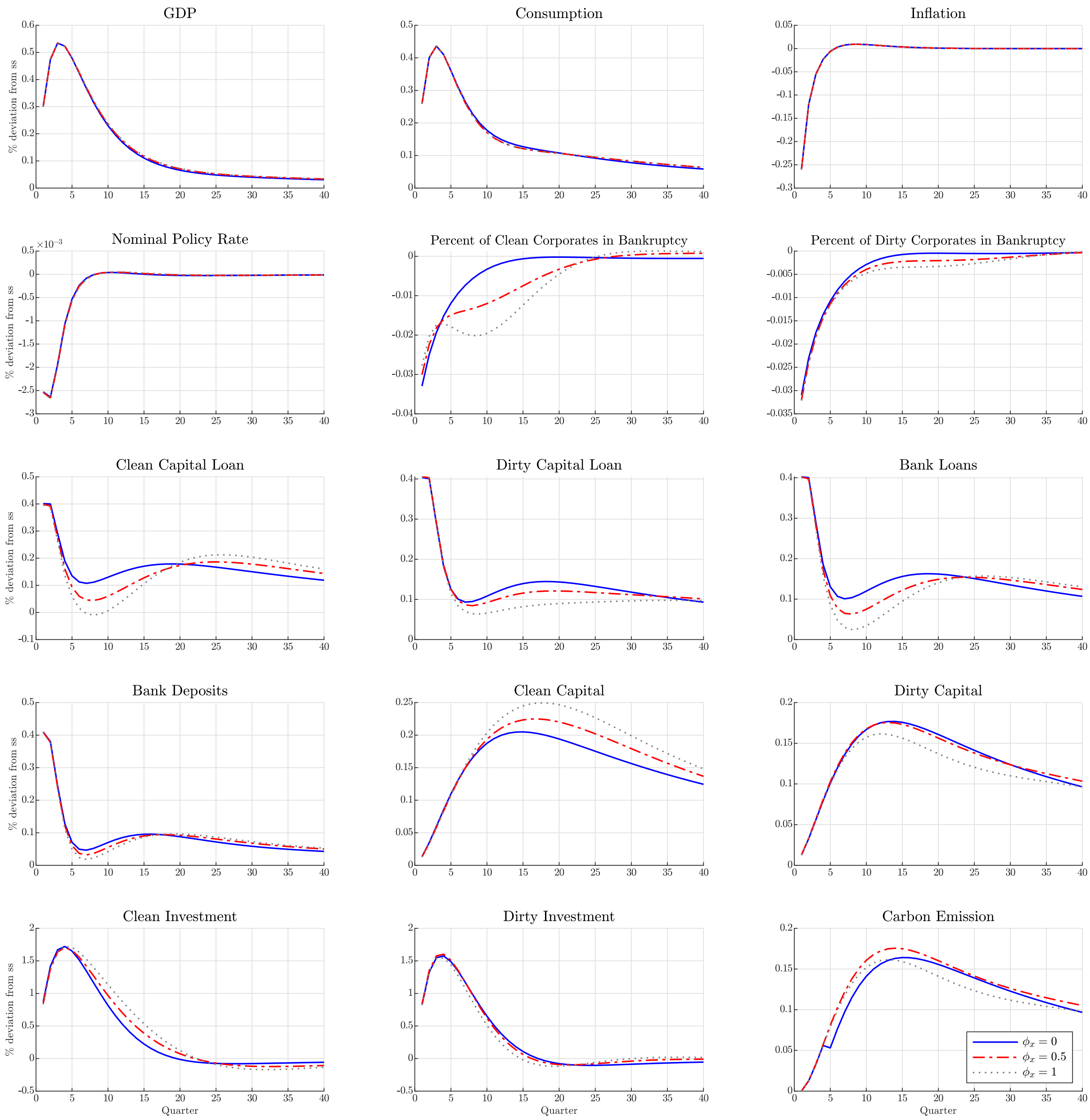

Figure 4: Carbon tax shock versus emission-elastic lending rates

Note: This figure shows the impulse responses of key variables following a positive 1% technology shock (deterministic) in period 1. The economy further faces a positive anticipated 1% carbon tax shock in quarter 5 (represented by the blue line). The carbon tax shock is temporary. The other lines represent economy responses devoid of carbon tax shock. Instead, the remaining lines represent responses with emission-elastic lending rates.

8 Conclusion

This paper studies a two-sector New Keynesian DSGE model with a full-fledged banking sector. Our model features both clean and dirty capitals. Commercial banks provide favourable loan terms to firms using clean capital for production through differentiated lending rates. We analyse the implications of this emission-elastic lending rate on social welfare and commercial banks' profits through simulating the economy's responses to different kinds of shocks.

We find that if the decision of the emission-elastic lending rate is up to commercial banks, welfare loss is incurred. By contrast, when the social planner decides the optimal emission-elastic lending rate, welfare improvement is possible. However, social welfare improvement with emission-elastic lending rates can be realized only when agents sufficiently "care" about the negative externality from emissions. Additionally, emission-elastic lending rate can act as a substitute for carbon tax in moving the firms towards cleaner production.

References

Acemoglu, D., Aghion, P., Bursztyn, L., & Hemous, D. (2012). The environment and directed technical change. *American Economic Review*, 102(1), 131–66.

Angelopoulos, K., Economides, G., & Philippopoulos, A. (2013). First-and second-best allocations under economic and environmental uncertainty. *International Tax and Public Finance*, 20(3), 360–380.

Annicchiarico, B., Carattini, S., Fischer, C., & Heutel, G. (2021). Business cycles and environmental policy: Literature review and policy implications.

Annicchiarico, B. & Di Dio, F. (2015). Environmental policy and macroeconomic dynamics in a new keynesian model. *Journal of Environmental Economics and Management*, 69, 1–21.

Annicchiarico, B., Di Dio, F., & Diluiso, F. (2022). Climate actions, market beliefs and monetary policy.

Annicchiarico, B. & Diluiso, F. (2019). International transmission of the business cycle and environmental policy. *Resource and Energy Economics*, 58, 101112.

Barrage, L. (2020). Optimal dynamic carbon taxes in a climate–economy model with distortionary fiscal policy. *The Review of Economic Studies*, 87(1), 1–39.

Barrdear, J. & Kumhof, M. (2021). The macroeconomics of central bank digital currencies. *Journal of Economic Dynamics and Control*, (pp. 104148).

Benes, J. & Kumhof, M. (2015). Risky bank lending and countercyclical capital buffers. *Journal of Economic Dynamics and Control*, 58, 58–80.

Benmir, G. & Roman, J. (2020). *Policy interactions and the transition to clean technology*. Grantham Research Institute on Climate Change and the Environment.

Böhringer, C., Rivers, N., & Yonezawa, H. (2016). Vertical fiscal externalities and the environment. *Journal of Environmental Economics and Management*, 77, 51–74.

Borenstein, S., Bushnell, J., Wolak, F. A., & Zaragoza-Watkins, M. (2019). Expecting the unexpected: Emissions uncertainty and environmental market design. *American Economic Review*, 109(11), 3953–77.

Calvo, G. A. (1983). Staggered prices in a utility-maximizing framework. *Journal of monetary Economics*, 12(3), 383–398.

Campiglio, E., Dafermos, Y., Monnin, P., Ryan-Collins, J., Schotten, G., & Tanaka, M. (2018). Climate change challenges for central banks and financial regulators. *Nature Climate Change*, 8(6), 462–468.

Carattini, S., Heutel, G., & Melkadze, G. (2021). *Climate policy, financial frictions, and transition risk*. Technical report, National Bureau of Economic Research.

Carney, M. (2015). Breaking the tragedy of the horizon–climate change and financial stability. *Speech given at Lloyd's of London*, 29, 220–230.

de France, B. (2019). Greening the financial system: The new frontier. *Financial Stability Review. Banque de France*.

De Gouvello, C. & Zelenko, I. (2010). *A financing facility for low-carbon development*. Number 203. World Bank Publications.

Diluiso, F., Annicchiarico, B., Kalkuhl, M., & Minx, J. C. (2020). Climate actions and stranded assets: The role of financial regulation and monetary policy.

Diluiso, F., Annicchiarico, B., Kalkuhl, M., & Minx, J. C. (2021). Climate actions and macro-financial stability: The role of central banks. *Journal of Environmental Economics and Management*, 110, 102548.

Dissou, Y. & Karnizova, L. (2016). Emissions cap or emissions tax? a multi-sector business cycle analysis. *Journal of Environmental Economics and Management*, 79, 169–188.

Economides, G. & Xepapadeas, A. (2018). Monetary policy under climate change.

Ferrari, A. & Nispi Landi, V. (2021). Whatever it takes to save the planet? central banks and unconventional green policy. *Central Banks and Unconventional Green Policy (February 15, 2021). Bank of Italy Temi di Discussione (Working Paper) No*, 1320.

Fischer, C. & Heutel, G. (2013). Environmental macroeconomics: Environmental policy, business cycles, and directed technical change. *Annu. Rev. Resour. Econ.*, 5(1), 197–210.

Fischer, C. & Springborn, M. (2011). Emissions targets and the real business cycle: Intensity targets versus caps or taxes. *Journal of Environmental Economics and Management*, 62(3), 352–366.

George, A., Huang, J., & Xie, T. (2021). Assessing the dual mandates of sustainability-linked monetary policy.

Gertler, M. & Karadi, P. (2011). A model of unconventional monetary policy. *Journal of Monetary Economics*, 58(1), 17–34.

Gertler, M. & Kiyotaki, N. (2010). Financial intermediation and credit policy in business cycle analysis. In *Handbook of monetary economics*, volume 3 (pp. 547–599). Elsevier.

Heutel, G. (2012). How should environmental policy respond to business cycles? optimal policy under persistent productivity shocks. *Review of Economic Dynamics*, 15(2), 244–264.

Javadi, S. & Masum, A.-A. (2021). The impact of climate change on the cost of bank loans. *Journal of Corporate Finance*, 69, 102019.

Pan, D. (2019). The economic and environmental effects of green financial policy in china: A dsge approach. *Available at SSRN 3486211*.

Pan, D., Chen, C., Grubb, M., & Wang, Y. (2021). Financial policy, green transition and recovery after the covid-19. *Green Transition and Recovery after the COVID-19 (February 22, 2021)*.

Punzi, M. T. (2018). Role of bank lending in financing green projects: A dynamic stochastic general equilibrium approach.

Rozenberg, J., Vogt-Schilb, A., & Hallegatte, S. (2014). Irreversible investment and transition to clean capital. *World Bank Policy Research Working Paper*.

Shmelev, S. E. & Speck, S. U. (2018). Green fiscal reform in sweden: econometric assessment of the carbon and energy taxation scheme. *Renewable and Sustainable Energy Reviews*, 90, 969–981.

Smets, F. & Wouters, R. (2003). An estimated dynamic stochastic general equilibrium model of the euro area. *Journal of the European Economic Association*, 1(5), 1123–1175.

Spiganti, A. & Comerford, D. (2020). The carbon bubble: climate policy in a fire-sale model of deleveraging. *European Univesrity Institute MWP Working Paper*.

van der Ploeg, F. (2020). Macro-financial implications of climate change and the carbon transition. In *Conference in ECB Forum on Central Banking* (pp. 90–142).

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 Other figures in welfare analysis

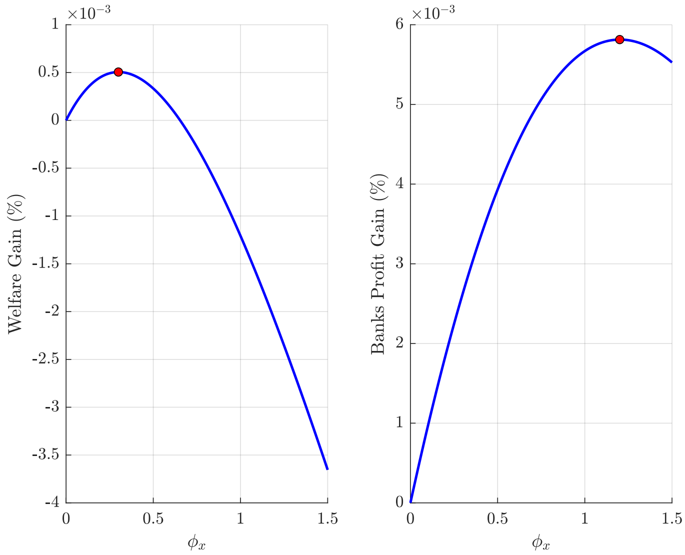

Figure 5: Welfare and banks pre-dividend analysis for supply shock

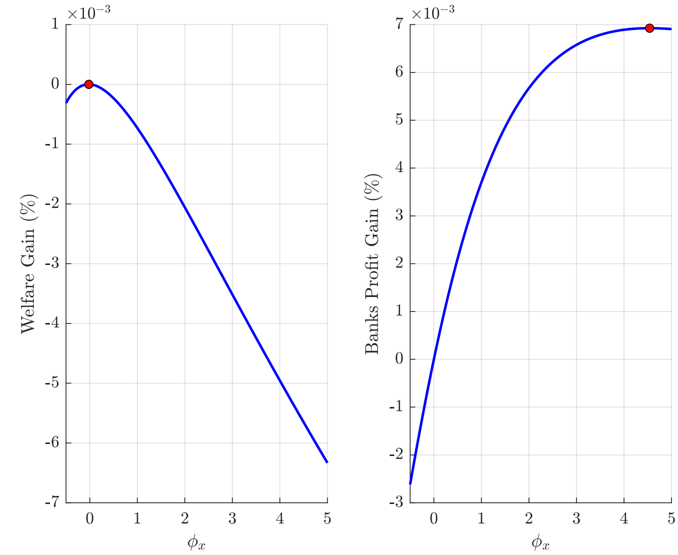

Figure 6: Welfare and banks pre-dividend analysis for demand shock

C Other figures with carbon tax shocks

The financial sector instability becomes marginal when emission-elastic lending rate is enforced together with a carbon tax shock. Figure 7 shows the impulse responses following a positive one standard deviation carbon tax shock. The exogenous rise in carbon prices makes dirty capital expensive. Firms' demand less dirty capital and emissions decline as a result. The black and red lines reveal that the enforcement of emission-elastic lending rate reduces emission volatility. As such, fig. 7 shows a smoother dip in emissions as ϕ_x increases. The financial sector distortions stemming from emission-elastic lending rates (evident from the responses of bank loans and deposits) are muted in the context of carbon tax shock. As in Carattini et al. (2021), the direct takeaway of this result is that the lending spread can mitigate the financial sector instability caused by the carbon tax shock.

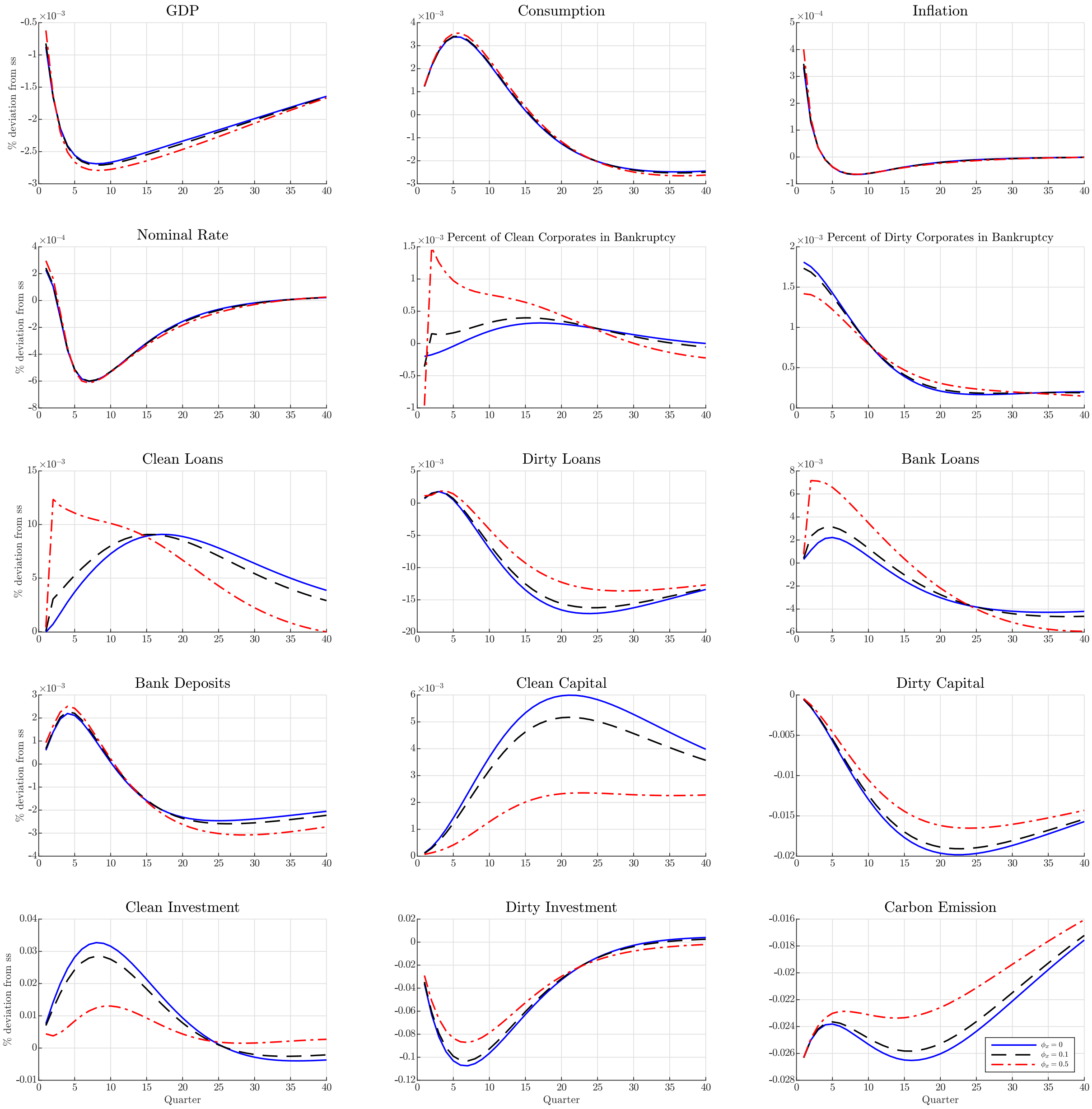

Figure 7: Carbon tax shock with emission-elastic lending rates

Note: This figure shows the impulse responses of key variables following a positive one standard deviation carbon tax shock with emission-elastic lending rates.