Can Sustainability-Linked Lending Reconcile Environmental and Financial Motives?⋆

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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 incorporate an interest spread responding elastically to carbon emissions: Banks offer lower lending rates to clean capital investment agencies when emission growth exceeds a target level. We find that while banks' offering emission-elastic lending rate (EELR) is consistent with the regulator's welfare objective, there is a tendency for banks to overreact to carbon emissions, resulting in increased loan volume, and thus, uncertainties in the financial sector. Although EELR faces more financial sector uncertainty, it outperforms Green Capital Requirements (GCR) in lowering the economic risk associated with the green transition.

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

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1. Introduction

> *"Financial regulators such as central banks can motivate banks to provide environment-friendly projects with easier access to capital."*
>
> —World Bank Blogs (April 27, 2020)

In recent years, many commercial banks around the world 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 funding to activities that reduce 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 (Euromoney, 2022; Mckinsey, 2022a; ABNAMRO, 2023; OCBC, 2023). Despite the active engagement of commercial banks in reducing financed emissions, a comprehensive exploration of the impacts of such initiatives is, nevertheless, limited.

The purpose of this paper is to provide one of the first attempts to investigate the economic, environmental and financial implications of such preferential lending rates, which we term the **emission-elastic**

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lending rate (EELR).[1] To perform our analysis, we develop an environmental-DSGE (E-DSGE) model where capital investment agencies (corporates) borrow from banks to finance capital purchases. We follow Benes and Kumhof (2015) to model the banking sector using the financing through money creation channel. Specifically, banks create deposits to fund loans rather than banks borrowing from depositors and lending to borrowers. This ingredient makes the changes in credit associated with the EELR funded by the changes in deposits. This directly impacts social welfare as deposits are part of the households' lifetime utility function (households prefer financial sector certainty through stable deposit balances). The borrowers in our model comprise two types of capital investment agencies 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 agencies and use them as production inputs. Emissions are a by-product of dirty capital usage (Heutel, 2012). Banks provide preferential lending rate treatment to clean capital investment agencies through the EELR when emission growth exceeds the target. The EELR coefficient determines the response of clean lending rates to emission growth.

Banks play a central role in financing. We identify three critical implications of banks' prerogative in offering the EELR to corporations that engage in clean capital purchases. First, the lower financing cost makes clean capital inputs cheaper and helps firms offset emission abatement costs. Consequently, firms are incentivised to substitute dirty capital with clean capital in production, resulting in emission reduction. Second, favourable lending rates increase the demand for corporate loans to finance clean capital purchases. The rise in loan demand expands aggregate loan volume, which can help offset the banks' lower interest income due to its differentiated lending rate initiative. Hence, the EELR can increase banks' profit margins. Finally, the issuance of the EELR is a double-edged sword. Although such preferential lending terms reduce emissions and help banks increase profit margins, improving social welfare is not akin to increasing bank profits. The expansion in lending following the issuance of the EELR raises the household's fears of financial sector uncertainty.

We perform three quantitative analyses using the aforementioned framework on the EELR coefficient. First, we conduct a simulation exercise to compare the socially optimal EELR where the regulator determines the EELR coefficient to maximize social welfare, and the competitive EELR where commercial banks choose the value of the EELR coefficient that maximises their profits. The key finding from this exercise is that there is a misalignment between competitive and socially optimal EELR. If it were up to commercial banks to decide, the EELR coefficient would always overshoot the socially optimal level. The intuition for this result is that a higher EELR coefficient tends to increase bank profits by reducing the interest rate of clean loans, which, in turn, increases the demand for clean loans. The latter more than offsets the former, thus increasing bank profits.

Our second exercise compares the economic, environmental and financial impacts of the EELR and green capital requirements (GCR). The latter is a popular financial policy that adjusts the risk weight of clean and dirty loans to either penalise dirty loans or make clean loans more affordable to help economies in their green transition. We find that: GCR are associated with greater financial stability due to stricter regulations on capital; The policy combination of carbon taxes and the EELR delivers a higher welfare than the combination of carbon taxes and GCR, since the former leads to a greater reduction in both the stock and volatility of emissions, the benefits of which outweigh the losses from higher financial instability, contributing to greater welfare; Neither the EELR nor GCR can replace the carbon tax as alternative policy tools.

Finally, we analyse the green transitional risk associated with the EELR and GCR. This exercise can

[1] Climate Bonds Standard Version 4.0 in England and Wales offers certification of the environmental credentials of specific projects, assets, or activities under the Climate Bonds sector-specific criteria.

be interpreted as a change in climate policy for countries that did not pay attention to climate risks previously. Specifically, we consider the introduction of an unexpected carbon tax shock to an economy that did not impose such a tax before. Our analysis demonstrates that the risk of green transition is lower when the EELR is implemented compared to the case when GCR is implemented. However, the latter is associated with fewer distortions in the banking sector than the former.

Our paper makes three main contributions to the literature on the role of commercial banks in greening the economy. First, we are the first to evaluate the economic and environmental implications of the recent initiative by commercial banks to offer preferential lending rates to corporates that engage in activities that reduce emissions. We develop a novel framework of the EELR, where the loan interest rate to clean capital investment agencies is tied to emission growth.[2] Our second contribution focuses on analyzing the role of lending rates and their dynamic equilibrium outcomes in the context of the EELR. We leverage our dynamic results to elucidate the transmission mechanism associated with the EELR. Finally, we perform a comparative analysis between the EELR and GCR within a framework that closely resembles the EELR. In this framework, we represent GCR as a green supporting factor, where the risk weight on clean loans decreases when the emission growth exceeds the target.

1.1. 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 green policies (Fischer and Springborn, 2011; Heutel, 2012; Annicchiarico and Di Dio, 2015; Dissou and Karnizova, 2016; Pan, 2019; Barrage, 2020; Diluiso et al., 2020; Annicchiarico et al., 2022; George et al., 2022).[3] Angelopoulos et al. (2013) and Fischer and 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. Annicchiarico and Di Dio (2015) study the dynamics of an economy under different environmental policy regimes in a New Keynesian model with nominal and real uncertainty. Along a different dimension, Dissou and Karnizova (2016) construct a multi-sector model to investigate the implications of different climate policies in the presence of multiple macroeconomic uncertainties. Later, Annicchiarico and Diluiso (2019) set up a two-country E-DSGE model to study the international transmission of the business cycle. George et al. (2022) examine the role of sustainability-linked monetary policy through collateral constraint and interest rates on emissions and social welfare. Giovanardi and Kaldorf (2023) examine the preferential treatment of green bonds within the central bank collateral framework. Our paper expands upon the current E-DSGE literature by introducing a two-sector model in which emissions result from dirty capital usage. We propose a novel framework incorporating the EELR, whereby banks reduce lending rates for clean capital investment agencies when emission growth surpasses the predefined target. We then use this framework to investigate whether sustainability-linked lending modelled as EELR can effectively align environmental and financial objectives. This analysis allows for a comprehensive exploration of how the banking sector can strategically channel loans towards environmentally sustainable production.

Second, our paper is also related to the literature on financial transition risk and environmental policy as the economy moves towards cleaner production (Carney, 2015; Campiglio et al., 2018; Punzi, 2018; de France, 2019; DOrazio and Valente, 2019; Benmir and Roman, 2020; van der Ploeg, 2020; Ferrari and Landi, 2023). The paper by Comerford and Spiganti (2023) is the first to investigate transition risk by incorporating the concept of a carbon bubble into a macroeconomic model that also incorporates

[2]A related paper in George et al. (2022) ties the overall interest rates to emission growth. In contrast, our study delineates clean and dirty capital lending rates using EELR framework where banks lower the clean lending rate when emission growth exceeds the target.

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

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 macroprudential policy to support green financing. For example, Ferrari and Landi (2023) 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. There exists literature focusing on the intersection of macroeconomic policy and environmental policy. For example, Economides and 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. Iovino et al. (2021) examine the relationship between corporate tax policy and carbon emissions. Annicchiarico et al. (2023) compare the welfare cost of business cycles in a model subject to cap-and-trade schemes or carbon taxes. They also analyse the performance of welfare-maximising rules for environmental and macroprudential policies. Our paper differs from previous studies by considering the impact of banks' differentiated lending rates to clean and dirty corporations on the transition to a green economy.

Our study is closely related to Diluiso et al. (2021) and Carattini et al. (2023) who also incorporate the banking sector into an E-DSGE model to examine the role of financial frictions in the design of climate policy. While Diluiso et al. (2021) and Carattini et al. (2023) examine the macro-financial implications of financial sector regulation on the green transition risk, our paper instead focuses on a recent initiative from commercial banks to offer preferential lending rates to corporations 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 one of the first attempts to fill this gap.

Contrary to Diluiso et al. (2021) and Carattini et al. (2023), which use Gertler and Kiyotaki (2010) and Gertler and Karadi (2011) to model banks as holders of risky equity, we follow the Benes and Kumhof (2015) setup where banks are lenders. The assumption of banks as holders of risky equity applies more to shadow banks than commercial banks. Hence, our setup presents a more realistic model of commercial banks. Another critical difference between the two kinds of banking framework pertains to the precise role of banks. Banks in Gertler and Kiyotaki (2010) and Gertler and Karadi (2011) act as intermediaries of loanable funds where they receive deposits from savers before lending the same to borrowers. In contrast, Benes and Kumhof (2015) setup follows the financing through money creation (FMC) channel where banks create deposits to fund loans. Such a realistic assumption (supported by central bank publications) plays a vital role in understanding the implications of loan dynamics associated with EELR. With the FMC model transmission, banks create deposits to fund the loan increases that arise from offering lower interest rates on clean loans. The financial stability outcomes associated with EELR can be better captured with the FMC model. Additionally, the deposits in utility function ensure that households are sensitive to financial sector instability. In short, our modelling setup makes sure that social welfare assessments include economic, financial and environmental outcomes.

The remainder of the paper proceeds as follows. Section 2 outlines the E-DSGE model featuring a banking sector offering the EELR and provides details regarding the model's parameterization. In Section 3, we present the findings related to social welfare and bank profits associated with the EELR, along with insights into equilibrium dynamics. Section 4 compares EELR with GCR and shows the transition to a greener economy, emphasizing the role of the EELR. Finally, Section 5 concludes.

2. Model

Our model constitutes a banking sector that lends to capital investment agencies to finance capital purchases. We extend the framework in Benes and Kumhof (2015) to include clean and dirty capital investment agencies. Banks differentiate lending rates between clean and dirty capital investment agencies through the emission-elastic lending rate (EELR). Firms rent capital from both types of capital investment agencies and use them as inputs in production (George et al., 2022). The production of the dirty sector is positively correlated with the stock of pollution, as the usage of dirty capital generates carbon emissions. In contrast, the clean sector can produce without emitting carbon.

Household. The household derives utility from external consumption habits and deposit holdings while facing disutility from labour supply and carbon emissions. A representative household seeks to maximise its expected lifetime 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 the elasticity of substitution ϵ, ν is the degree of habit persistence, n_t is labour 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 labour supply, deposit holdings and emissions in the utility function. We model the disutility of emissions, following Acemoglu et al. (2012), Pan et al. (2021) and Chan and Punzi (2023). η_h is the Frisch elasticity of the labour supply.

The budget of the household in period t is:

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

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 are as follows:

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

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 Equation (3) also shows that bonds and deposits from period $t-1$ earn real interest at rates r_t^b and r_t^{d}, respectively. In our model, the real interest r_t^x on any asset or liability x corresponds to the inflation-adjusted nominal interest rate through the Fisher equation $r_t^x = \frac{i_{t-1}^x}{\pi_t}$, where $\pi_t = \frac{P_t}{P_{t-1}}$ is the inflation of the gross price level P_t.

The household maximises Equation (1) subject to Equation (3). The first-order conditions are listed below:

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

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

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

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

Capital goods firms. Both clean and dirty capital stocks are produced by capital goods firms, with 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 the same across both types of capital.

The production of capital goods is subject to investment 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

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

$M_{0,t}$ 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 optimization 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 type of capital investment agencies is indexed by j with $j \in \{c, d\}$. Capital investment agencies receive rental income at a real rate r_{jt}^k by renting capital of type j 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 into a loan contract with banks to secure loans at a nominal retail interest rate i^r_{jt}. Capital investment agencies are subject to an idiosyncratic shock ω^k_{jt+1} following a log-normal distribution with $ln(\omega^k_{jt+1}) \sim N\left(1, {\sigma^k_{jt}}^2\right)$, which changes k_{jt} to $\omega^k_{jt+1}k_{jt}$. The cumulative and probability density functions of ω^k_{jt+1} are denoted by $\mathfrak{F}^k_t(\omega^k_{jt+1})$ and $\mathfrak{f}^k_t(\omega^k_{jt+1})$, respectively. Capital investment agencies that receive a shock ω^k_{jt+1} below a cut-off ϖ^k_{jt+1} cannot 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 a 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:

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

where the wholesale real interest payments 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 that can pay the pre-committed retail rate. The second term refers to the cash flow from borrowers who become bankrupt, where banks recover only $(1-\xi)$ portion of the return on capital investment. The remaining ξ portion is paid to households as fees for managing the bankruptcy (see $\boldsymbol{\Omega}_t$ in Equation (4)).

We rewrite the zero expected bank profit condition (Equation (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 $G_{jt+1} = \int_0^{\varpi^k_{jt+1}} \omega^k_{jt+1}\mathfrak{f}^k_t(\omega^k_{jt+1})d\omega^k_{jt+1}$, and

$$\Gamma_{jt+1} \equiv \int_0^{\varpi^k_{jt+1}} \omega^k_{jt+1}\mathfrak{f}^k_t(\omega^k_{jt+1})d\omega^k_{jt+1} + \varpi^k_{jt+1}\int_{\varpi^k_{jt+1}}^{\infty} \mathfrak{f}^k_t(\omega^k_{jt+1})d\omega^k_{jt+1}, \tag{19}$$

is the banks' share in type j capital earnings. This implies that the share of type j capital investment agencies in the capital earnings equals $1 - \Gamma_{jt+1}$. Thus, type j capital investment agency seeks to maximise its profits:

$$\max_{k_{jt}\overline{\omega}^k_{jt+1}} \mathbb{E}_t \left\{ (1-\Gamma_{t+1}) \frac{ret^k_{jt+1}}{\tilde{r}^l_{jt+1}} \frac{q_{jt}k_{jt}}{\mathsf{n}^k_{jt}} \right\}, \tag{20}$$

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

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

$$\mathbb{E}_t \left\{ (1-\Gamma_{dt+1}) \frac{ret^k_{dt+1}}{\tilde{r}^l_{dt+1}} + \frac{\Gamma'_{dt+1}}{\Gamma'_{dt+1} - \xi G'_{dt+1}} \left[\frac{ret^k_{dt+1}}{\tilde{r}^l_{dt+1}} (\Gamma_{dt+1} - \xi G_{dt+1}) - 1 \right] \right\} = 0, \tag{22}$$

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 Equation (15) evolves as:

$$\mathsf{n}^k_{jt} = \tilde{r}^l_{jt}\mathsf{n}^k_{jt} + (ret^k_{jt}(1-\xi G_{jt}) - \tilde{r}^l_{jt})q_{jt-1}k_{jt-1} - \zeta^k \mathsf{n}^k_{jt} + \mathfrak{L}_{jt}, \tag{23}$$

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

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

$$l_t = \mathsf{d}_t + \mathsf{n}^b_t, \tag{24}$$

where $l_t = l_{ct} + l_{dt}$ is the total loans issued, and n^b_t is the banks' net worth.

Returns from lending are subject to the solvency risk denoted by ω^b_{t+1}, which follows a log-normal distribution, i.e., $ln(\omega^b_{t+1}) \sim N\left(1, \sigma^{b^2}\right)$. Banks pay the penalty amounting to $\chi l_t \mathfrak{F}^b_t(\overline{\omega}^b_{t+1})$ in $t+1$, if the loan returns net of deposits interest payments and loan loss is less than the risk-weighted Minimum Capital Adequacy Ratio (MCAR) γ_t of the gross loan returns:

$$\sum_{j=c,d} \tilde{r}^l_{jt+1} l_{jt} - r^{\mathsf{d}}_{t+1}\mathsf{d}_t - \mathfrak{L}_{jt} < \gamma_t \sum_{j=c,d} \Psi^j \tilde{r}^l_{jt+1}\omega^b_{t+1}, \tag{25}$$

where Ψ^j is the risk weight of type j loan.

The cut-off solvency risk measure in period t is:

$$\overline{\omega}^b_t = \frac{r^{\mathsf{d}}_t \mathsf{d}_{t-1} + \mathfrak{L}_{jt}}{\sum_{j=c,k}(1-\Psi^j\gamma_{t-1})\tilde{r}^l_{jt} l_{jt-1}}. \tag{26}$$

A representative bank seeks to maximise the pre-dividend profits from lending:

$$\Pi^b = \max_{l_{ct}, l_{dt}} \mathbb{E}_t \left\{ \omega^b_{t+1} \sum_{j=c,d} \tilde{r}^l_{jt+1} l_{jt} - r^{\mathsf{d}}_{t+1}\mathsf{d}_t - \mathfrak{L}_{jt+1} - \chi l_t \mathfrak{F}^b_t(\overline{\omega}^b_{t+1}) \right\}. \tag{27}$$

Net worth in Equation (24) evolves as:

$$\mathsf{n}^b_t = \sum_{j=c,d} \tilde{r}^l_{jt} l_{jt-1} - r^{\mathsf{d}}_t \mathsf{d}_{t-1} - \mathfrak{L}_{jt} - \chi l_t \mathfrak{F}^b_t(\overline{\omega}^b_t) - \zeta^b \mathsf{n}^b_t, \tag{28}$$

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 Equation (27) subject to Equation (24). The resulting first-order conditions are:[4]

$$l_{ct}: \mathbb{E}_t \left\{ \tilde{r}^l_{ct+1} - r^{\mathsf{d}}_{t+1} - \chi \left(\mathfrak{F}^b_t(\overline{\omega}^b_{t+1}) + l_t \frac{\partial \mathfrak{F}^b_t(\overline{\omega}^b_{t+1})}{\partial l_{ct}} \right) \right\} = 0, \tag{29}$$

$$l_{dt}: \mathbb{E}_t \left\{ \tilde{r}^l_{dt+1} - r^{\mathsf{d}}_{t+1} - \chi \left(\mathfrak{F}^b_t(\overline{\omega}^b_{t+1}) + l_t \frac{\partial \mathfrak{F}^b_t(\overline{\omega}^b_{t+1})}{\partial l_{dt}} \right) \right\} = 0. \tag{30}$$

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

$$\tilde{i}^l_{ct} = i^l_{ct} \exp\left[-\phi_x \left(\frac{x_t}{x_{t-1}} - 1 \right) \right], \tag{31}$$

$$\tilde{i}^l_{dt} = i^l_{dt}, \tag{32}$$

where x_t is domestic carbon emission and ϕ_x is the EELR 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 investment 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 the EELR causes asymmetric effects on the loan demand from clean and dirty capital investment agencies. Lower borrowing costs stimulate clean capital investment agencies to finance more clean capital. In short, the EELR endogenously expands clean capital when emissions growth exceeds the target.

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

$$y_t(i) = A_t \left[1 - \Lambda\left(m_t\right) \right] n_t(i)^{1-\alpha} k_{t-1}(i)^{\alpha}, \tag{33}$$

where $\Lambda\left(m_t\right)$ is the damage function of global carbon emission stock m_t which takes the DICE from as in Annicchiarico and Di Dio (2015) and George et al. (2022):[5]

$$\Lambda\left(m_t\right) = \gamma_0 + \gamma_1 m_t + \gamma_2 m_t^2. \tag{34}$$

$k_t(i)$ in Equation (33) is a CES composite of clean and dirty capital inputs for variety i as follows:

$$k_t(i) = \left[\upsilon^{1/\varphi} k_{dt}(i)^{1-1/\varphi} + (1-\upsilon)^{1/\varphi} (A_c k_{ct}(i))^{1-1/\varphi} \right]^{\frac{\varphi}{\varphi-1}}, \tag{35}$$

where A_c is the productive efficiency of the clean capital to the dirty capital as in George et al. (2022), and φ captures the degree of substitution elasticity between clean and dirty capital.

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

[5] Unlike the Dynamic Integrated Model of Climate and the Economy (DICE) model discussed in Nordhaus (2008), our paper considers a different approach where atmospheric carbon levels influence the output damage. On the contrary, the DICE model associates output damage with mean surface temperature, which, in turn, depends on atmospheric carbon levels.

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

$$x_t(i) = [1 - \vartheta_t(i)]\, \phi_d k_{dt-1}(i), \tag{36}$$

where $\vartheta_t(i)$ is the effort of the 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:

$$\Pi_t^m(i) = \max_{n_t(i),k_{dt}(i),k_{ct}(i),\vartheta_t(i)} y_t(i) - w_t n_t(i) - r_{dt}^k k_{dt-1}(i) - r_{ct}^k k_{ct-1}(i) - \tau_t^x x_t(i) - \mathcal{C}_t^A(i), \tag{37}$$

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

$$\mathcal{C}_t^A(i) = \phi_1 \vartheta_t(i)^{\phi_2} k_{dt-1}(i). \tag{38}$$

The final goods firm maximises Equation (37) subject to Equations (33), (35), (36) and (38). The resulting first-order conditions are:

$$n_t(i) : (1-\alpha)\,\frac{y_t(i)}{n_t(i)} = \frac{w_t}{mc_t(i)}, \tag{39}$$

$$k_{ct-1}(i) : \alpha\,(1-\upsilon)^{1/\varphi}\frac{y_t(i)}{k_{ct-1}(i)}\left(\frac{A_c k_{ct-1}(i)}{k_{t-1}(i)}\right)^{-1/\varphi} = \frac{r_{ct}^k}{mc_t(i)}, \tag{40}$$

$$k_{dt-1}(i) : \alpha\,\upsilon^{1/\varphi}\frac{y_t(i)}{k_{dt-1}(i)}\left(\frac{k_{dt-1}(i)}{k_{t-1}(i)}\right)^{-1/\varphi} = \frac{\tilde{r}_{dt}^k(i)}{mc_t(i)}, \tag{41}$$

$$\vartheta_t(i) : \tau_t^x \phi_d = \phi_1 \phi_2 \vartheta_t(i)^{\phi_2 - 1}, \tag{42}$$

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. Equation (42) reveals that all firms choose similar levels of abatement effort. Consequently, the adjusted dirty capital rent is also similar across firms. All four optimality conditions imply that all firms make similar choices on labour, clean capital, dirty capital and abatement efforts. Therefore, 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 by:

$$\tilde{\pi}_t = \frac{\epsilon}{\epsilon - 1}\frac{\sum_{h=0}^{\infty} \theta^h \mathbb{E}_t Q_{t,t+h}\left(\frac{p_t}{p_{t+h}}\right)^{-\epsilon} y_{t+h} mc_{t+h|t}}{\sum_{h=0}^{\infty} \theta^h \mathbb{E}_t Q_{t,t+h}\left(\frac{p_t}{p_{t+h}}\right)^{1-\epsilon} y_{t+h}}, \tag{43}$$

where $\tilde{\pi}_t = \frac{\tilde{p}_t}{p_t}$ is the optimal price divided by the 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:

$$1 = \theta \pi_t^{\epsilon - 1} + (1-\theta)\tilde{\pi}_t^{1-\epsilon}. \tag{44}$$

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

$$\tau_t^{ls} + \tau_t^x x_t + \mathcal{T}_t^b = g_t. \tag{45}$$

$\mathcal{T}_t^b = \chi l_t \mathfrak{F}_t^b(\varpi_{t+1}^b)$ 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 nominal policy rate (nominal interest rate on bonds) follows the below Taylor rule for inflation and output targeting:

$$i_t^b = \left(i_{t-1}^b\right)^{\rho_i} \left[\frac{1}{\beta}\left(\frac{\pi_t \pi_{t+1} \pi_{t+2} \pi_{t+3}}{\bar{\pi}^4}\right)^{\phi_\pi} \left(\frac{y_t}{\bar{y}}\right)^{\phi_y}\right]^{1-\rho_i}, \tag{46}$$

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

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

$$\gamma_t = \bar{\gamma}\left(\frac{l_t}{\bar{l}}\right)^{\phi_l}, \tag{47}$$

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

Equilibrium. In equilibrium, the final goods market clears:

$$y_t = c_t + g_t + \mathcal{C}_t^A + \sum_{j \in \{c,d\}} I_{jt}\left[1 + \frac{\phi_I}{2}\left(\frac{I_{jt}}{I_{jt-1}} - 1\right)^2\right]. \tag{48}$$

Aggregation of all varieties of output in Equation (33) yields:

$$s_t y_t = A_t \left[1 - \Lambda\left(m_t\right)\right] n_t^{1-\alpha} k_{t-1}^{\alpha}, \tag{49}$$

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:

$$s_t = (1-\theta)\tilde{\pi}_t{}^{-\epsilon} + \theta \pi_t{}^{\epsilon} s_{t-1}. \tag{50}$$

At a rate of pollution decay denoted by δ_m, the global emission stock naturally decreases over time. However, new emissions continue to accumulate, contributing to the overall emission stock:

$$m_t = \delta_m m_{t-1} + x_t + x^*, \tag{51}$$

where x_t is the overall emission produced by dirty firms and x^* is the emission from the rest of the world (ROW).

Exogenous shocks. We consider two exogenous shocks in our model: shocks to technology A_t (supply shock) and consumption preference z_t (demand shock). Vector $\mathbf{e}_t$ comprise the two shocks which follow an AR(1) process:

$$\ln(\mathbf{e}_t) = \rho_{\mathbf{e}} \ln(\mathbf{e}_t) + (1-\rho_{\mathbf{e}})\ln(\bar{\mathbf{e}}) + \varepsilon_{\mathbf{e}}, \quad \varepsilon_{\mathbf{e}} \sim N(0, \sigma_{\mathbf{e}}^2). \tag{52}$$

2.1. Parameterisation

We calibrate our model on the US economy using parameter values from the past literature at the quarterly frequency. Table 1 shows the parameter values. In line with Smets and 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. The weight of labour hours and deposits in the utility function (μ_h, μ_d) align with Benes and Kumhof (2015).

We set the emission weight in the utility function μ_x at 1. We later showcase the sensitivity analysis associated with the values of μ_x. Following George et al. (2022), we set the capital share in production α as 0.33, capital depreciation rate δ as 0.02, investment adjustment cost ϕ_I as 2, the elasticity of substitution (EoS) between goods ϵ as 6, and the fraction of firms which cannot reset price in the current period θ as 0.75. The steady-state government spending to GDP ratio is 18% (Barrdear and Kumhof, 2021).

Table 1: Calibration parameterization

Parameter	Value	Description
NK parameters		
β	0.9975	Discount factor
ν	0.70	Habit persistence
η_h	1	Frisch elasticity
μ_h	0.9524	Labor disutility
μ_d	0.0042	Deposit utility
μ_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
s_g	0.18	Government spending to GDP ratio
Environmental parameters		
ϕ_1	0.185	Abatement cost parameters
ϕ_2	2.8	
γ_0	0.0295	Damage function coefficient
γ_1	9.10E-6	Damage function coefficient
γ_2	1.95E-8	Damage function coefficient
δ_m	0.99706	Pollution decay rate
υ	0.5	Dirty capital parameter in composite capital function
φ	2	Elasticity of substitution between clean and dirty capital
x^*	1.44	Emissions in the ROW
ϕ_d	0.09	Emission per unit of dirty capital
A_c	1	The relative productive efficiency of clean capital to dirty capital
Banking sector parameters		
ζ^k	0.02	Share of capital investment agency net-worth as dividends
χ	0.0033	MCAR penalty
δ^b	0.0146	Share of bank net worth as dividends
σ^b	0.0140	Bank riskiness
ξ	0.1771	Share of capital investment return paid for bankruptcy administration
$\overline{\gamma}$	0.08	MCAR ratio steady state
Ψ^c	1	The risk weight of clean loan
Ψ^d	1	The risk weight of dirty loan
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

We follow Annicchiarico and Di Dio (2015); Punzi (2018); George et al. (2022) to set the E-DSGE parameters. The abatement cost parameters - ϕ_1 and ϕ_2, damage function parameters - γ_1 and γ_2, and pollution decay rate ϑ follow Annicchiarico and Di Dio (2015) who calibrate the parameters to the US economy.We set the dirty capital weight and elasticity of substitution parameters in the CES capital composite (υ, φ) and the carbon emissions per unit of dirty capital ϕ_d as per Papageorgiou et al. (2017);

George et al. (2022).[6] As in Ferrari and Landi (2023), we assume a steady-state carbon stock of 867 gigatons of atmospheric carbon, denoted as $\overline{m}$. The damages from carbon stock amount to 5.2% of output in the steady state (i.e., $\Lambda(m_t) = 0.052$). We follow George et al. (2022) to set the steady-state carbon tax at 0.0216, which implies \$27.6 per ton of carbon dioxide, closely matching the social cost of carbon, \$31 per tone of carbon dioxide, estimated by Nordhaus (2017).[7] Following Punzi (2018), we assume the productive efficiencies of clean capital and dirty capital are equal, i.e. $A_c = 1$.

The banking sector parameters are calibrated based on Benes and Kumhof (2015). In accordance with the Basel-III mandates, we set the steady-state of capital requirement ratio as $\bar{\gamma} = 0.08$. The risk weights are symmetric and fixed at 1 for clean and dirty capital loans (Ψ_c, Ψ_d). This implies that the MCAR ratio is similar for both loan types. We relax this criterion later in the paper, where we compare the EELR with green capital requirements. The calibration of the monetary policy coefficients (ρ_i, ϕ_π and ϕ_y) and the macro-prudential policy parameter (ϕ_l) follow Benes and Kumhof (2015).

The shock parameters reported in Table 2 are calibrated to match the standard deviations and autocorrelation of the US macroeconomic data for 1990Q1-2020Q1.[8] Table 3 compares the data moments and the implied model moments from second-order perturbations around the stochastic steady state in Dynare 5.4. We compute the data moments using FRED database except for the correlations between emissions, GDP and GDP, debt which we source from Giovanardi and Kaldorf (2023).[9] 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	0.014
Consumption preference shock (z_t)	0.60	0.016

Table 3: Model fit

Moment	Model	Data	Source
Means			
Firm leverage	49%	40%	Giovanardi and Kaldorf (2023)
Firm default rate	1% p.a.	1% p.a.	Benes and Kumhof (2015)
Bank MCAR violation rate	2% p.a.	2% p.a.	Benes and Kumhof (2015)
Dynamics			
σ(GDP)	2.26	2.11	FRED
σ(Investment)	6.70	7.43	FRED
σ(Policy rate)	2.46	2.06	FRED
σ(Net worth of dirty firms)	5.93	6.11	FRED
$corr$(Emissions, GDP)	0.48	0.64	Giovanardi and Kaldorf (2023)
$corr$(GDP, investment)	0.78	0.80	FRED
$corr$(GDP, debt)	0.69	0.65	Giovanardi and Kaldorf (2023)

[6] We discuss the sensitivity of the elasticity of substitution between clean and dirty capital in Appendix B.

[7] We use the method in Carattini et al. (2023) to calculate the efficient carbon tax. Carbon tax in USD per ton of CO2 = Carbon tax in model units × [20 trillion USD / Annual output in model units] × [Emissions in model units / Steady-state stock level corresponding to quarterly emissions flow] / [3.67 tons CO2 / Ton of carbon].

[8] In Appendix C, we show the variance decomposition of the shocks. The technology shock explains most volatility in all key variables.

[9] The proxy variable for the risk-free rate (policy rate) is the 3-month treasury bill rate. The non-financial corporate net worth represents the net worth of dirty firms.

3. Implications of EELR

3.1. Social welfare and bank profits

Clean lending rates respond to emission growth in the EELR framework (see Equation (29)). The coefficient ϕ_x determines the response of the clean lending rate to emissions. A natural question is whether banks should have the autonomy to determine ϕ_x. To answer this question, we examine the effects of the EELR coefficient ϕ_x on bank profit and social welfare. We define bank profit as Π_t^b in Equation (27). Social welfare is the discounted value of the household lifetime expected utility:[10]

$$\mathcal{W}_t = \mathbb{E}_t \sum_{j=0}^{\infty} \beta^t u(c_{t+j}, n_{t+j}, \mathsf{d}_{t+j}, x_{t+j}). \tag{53}$$

We conduct a grid search for ϕ_x in two steps. First, we search for the value of ϕ_x that delivers the highest unconditional mean of Π_t^b using the range $\phi_x \in [0, 8]$ at increments of 0.01.[11] The ϕ_x that maximises bank profit, which we term the **competitive EELR**, equals 8. Banks opt for the competitive EELR if they have the autonomy to set the EELR coefficient. Second, we search for ϕ_x that maximises the unconditional mean of $\mathcal{W}_t$ over the same range $\phi_x \in [0, 8]$. **Socially optimal EELR** pertains to $\phi_x = 5.89$ which delivers the highest social welfare. If the regulator has autonomy in setting ϕ_x, she will opt for the socially optimal EELR. The positive ϕ_x values associated with the competitive and socially optimal EELR imply that welfare and bank profit improves with the EELR as compared to the **baseline** scenario of no EELR ($\phi_x = 0$), irrespective of whether banks or regulators have the EELR autonomy.

Table 4 reports the gains in bank profit and social welfare that correspond to the competitive and socially optimal EELR as compared to the baseline regime without the EELR. Bank profit gain (Δ bank profit) is defined as the percentage change in the unconditional mean of bank profit from the baseline to the competitive/socially optimal EELR. Welfare gain is defined using the concept of compensating consumption variation:

$$\Delta\text{welfare} = 100\left(1 - \exp\left[\frac{(\beta-1)\left(\mathcal{W}_t^{\text{X EELR}} - \mathcal{W}_t^{\text{Baseline}}\right)}{1-\upsilon}\right]\right), \quad \text{X} \in \big(\text{Competitive, Socially optimal}\big), \tag{54}$$

where Δ welfare is the percentage of consumption goods that the household is willing to forgo to remain indifferent between baseline and the competitive/socially optimal EELR. A positive value indicates a gain in welfare.

Table 4: Competitive and socially optimal EELR

	ϕ_x	Δ bank profit	Δ welfare	Δ σ(emission)	Δ σ(loan)	Δ σ(deposit)
Competitive EELR	8.00	0.2755	0.0931	-53.11	9.60	0.39
Socially optimal EELR	5.89	0.2221	0.0957	-47.30	7.35	0.32

Note: Δ welfare is the consumption equivalent measure with positive values indicating welfare gain. Δ bank profit refers to the percentage change in the mean moments of bank profit compared to the baseline of no EELR ($\phi_x = 0$). Rows with Δ σ report the percentage change in the standard deviation of key variables compared to the baseline. The moments are derived using second-order perturbations around the stochastic steady state in Dynare 5.4 with shocks to technology and consumption preference as specified in Section 2.1.

[10] In our paper, we have utilized a firm's carbon emissions x_t as a central factor in explaining utility. The focus lies in how the emission-elastic lending rate can alter a firm's carbon emission behaviour. Incorporating a firm's carbon emissions into the utility function is primarily based on our consideration of how a firm's actions impact the environment, allowing us to derive results at a regional level. We have also explored the possibility of incorporating the global carbon emissions stock m_t into the utility function, and our main results remain robust.

[11] We also experiment with larger upper bonds for the grid search, and all our qualitative results remain valid.

The most important finding of Table 4 is that there exists a positive gap for the value of ϕ_x between the competitive and socially optimal EELR. Specifically, there is an overshoot of the competitive EELR ϕ_x compared to the socially optimal EELR ϕ_x. This occurs because a larger value of ϕ_x tends to increase bank profits by reducing the interest rate of clean loans, which, in turn, increases the demand for clean loans. The latter more than offsets the former, thus increasing profits. In fact, bank profits increase monotonically with ϕ_x, which will be shown later in this section.

There is, however, a cost associated with higher ϕ_x. As clean lending rates are more responsive to emission growth, aggregate lending becomes more volatile as the demand for loans from capital investment agencies adapts to the changes in lending rates. With loans funding deposit creation (financing through money creation channel), aggregate deposit volatility rises. Indeed, Table 4 shows that the competitive EELR is associated with larger increases in deposit volatility than the socially optimal EELR. This financial instability reduces social welfare due to the household's preference towards financial stability, which is modelled by the deposit-in-utility function. Therefore, the greater financial instability under the competitive EELR reduces the size of the social welfare gain.

We now examine the gains in social welfare and bank profits when the value of ϕ_x changes. The left panel in Figure 1 plots the EELR coefficient on the horizontal axis and the corresponding welfare gain on the vertical axis. The right panel plots the EELR coefficient on the horizontal axis and the corresponding bank profit gain on the vertical axis. We observe that welfare gains initially rise with ϕ_x but start to decline once ϕ_x surpasses the socially optimal EELR ϕ_x at 5.89. In contrast, gains in bank profits increase at a decreasing rate when ϕ_x increases.

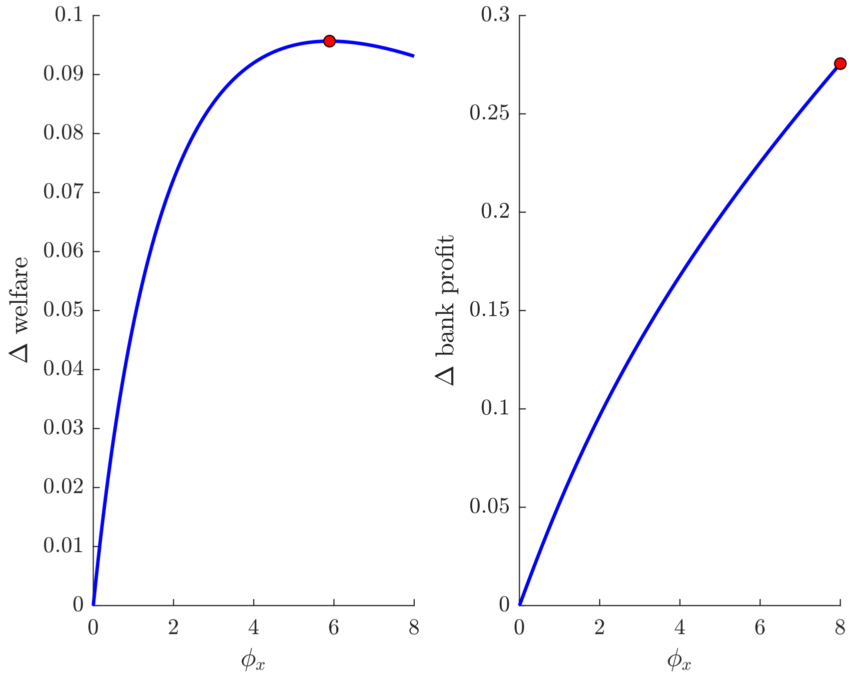

Figure 1: Dynamic plot of gains in social welfare and bank profit

These results suggest that there is a misalignment between a bank's choice of the EELR and the socially optimal level of the EELR. If it were up to commercial banks to make a decision on the EELR coefficient, they would always overshoot the socially optimal level. In the next section, we further examine the robustness of this result.

Individual shocks. The previous section studies an economy when technology and consumption preference shocks are present simultaneously. In this section, we examine whether our key findings remain valid when only one of the two shocks hits the economy. We perform grid searches as before to obtain the ϕ_x corresponding to the competitive and socially optimal EELR by considering one shock at a time. Table 5 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. We highlight three findings from the results. First and most importantly, the positive ϕ_x gap between the competitive and socially optimal EELR persists for both shocks. Consistent with our previous results, competitive EELR ϕ_x always overshoot the socially optimal EELR ϕ_x.[12] Second, the magnitude of bank profits and social welfare gains under the technology shock largely resembles that of the results in Table 4 pertaining to simultaneous shocks. This is expected as the technology shock accounts for most of the volatility of key variables.[13] Last, society suffers a welfare loss with the competitive EELR under the consumption preference shock. This contrasts with the technology shock result in Panel A where the socially optimal EELR is accompanied by social welfare gain. Section 3.2 elaborates more on the possible reasons for the welfare loss associated with the competitive EELR in the context of consumption preference shock.

Table 5: Competitive and socially optimal EELR: Individual shocks

	ϕ_x	Δ bank profit	Δ welfare
Panel A: Technology shock			
Competitive	8.00	0.2524	0.0985
Socially optimal	7.00	0.2301	0.0989
Panel B: Consumption preference shock			
Competitive	8.00	0.0235	-0.0054
Socially optimal	1.40	0.0058	0.0016

Note: Δ welfare is the consumption equivalent measure with positive values indicating welfare gain. Δ bank profit refers to the percentage change in the mean moments of bank profit compared to the baseline of no EELR ($\phi_x = 0$). The moments are derived using second-order perturbations around the stochastic steady state in Dynare 5.4 with shocks to technology and consumption preference as specified in Section 2.1.

3.2. Transmission mechanism

This section reports the dynamic properties of the EELR using; a) Baseline: No EELR, i.e. $\phi_x = 0$, b) Competitive EELR: ϕ_x set by commercial banks, c) Socially optimal EELR: Regulator sets the value of ϕ_x. We use the ϕ_x values of competitive and socially optimal EELR from Table 4 for the simulations.

Technology shock. Figure 2 shows the impulse responses of key variables following a 0.01 percent positive technology shock. The solid blue line represents the responses in the baseline scenario of no EELR, the black dotted line corresponds to the socially optimal EELR, and the red dashed line pertains to the competitive EELR.

We first discuss the dynamics in the baseline regime (solid blue line). An exogenous rise in productivity increases GDP and consumption. The increase in the aggregate supply of goods leads to deflation, causing the nominal policy rate to drop in response. Consequently, 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. The financing through the money creation channel (Benes and Kumhof, 2015; Barrdear and Kumhof, 2021) causes bank

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

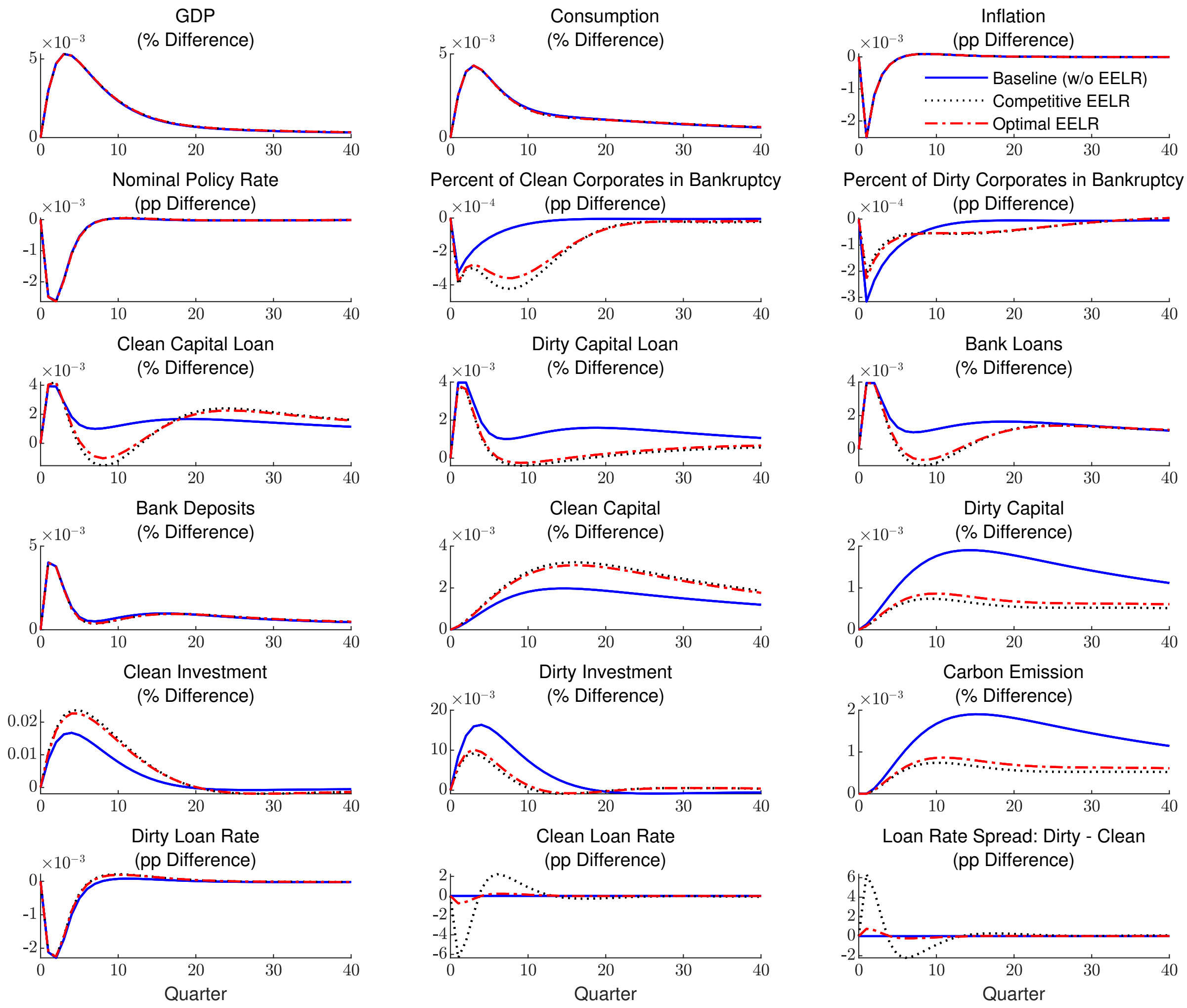

Figure 2: Technology shock

Note: This figure shows the impulse responses of key variables in response to a 0.01 percent positive technology shock.

deposits to rise in tandem with bank loans. Both types of capital and investment expand symmetrically. The increase in dirty capital worsens carbon emissions.

With the EELR (black dotted and red dashed lines), emission growth stemming from technology shock causes the spread between dirty and clean capital lending rates to widen, especially with the competitive EELR. Contrary to the baseline, the EELR creates asymmetric 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 the higher intensity of ϕ_x in the competitive regime. In fact, the hump shape in clean lending, which occurs a few periods after 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 favourable 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 with the EELR.

Although environmentally feasible, the EELR does not elicit financial stability. The clean capital loan volatility associated with the EELR makes aggregate bank lending more volatile. Consequently, bank deposit volatility also rises because of the financing through money creation channel where loans fund deposit creation (Benes and Kumhof, 2015). Volatility in deposits adversely impacts households as their lifetime utility function comprises deposits. In other words, the deposit volatility associated with the EELR, which adversely affects households, makes the regulator opt for a smaller ϕ_x (socially optimal EELR). Therefore, the socially optimal EELR ϕ_x is less than the competitive EELR ϕ_x.

As described previously in Section 3, there are gains in social welfare with the socially optimal EELR. Then, a natural question would be why such welfare improvements arise despite the deposit volatility associated with the EELR. The likely explanation lies in the other determinant of households' utility - emissions. From Equation (1), we see that households suffer disutility from emissions. The EELR helps reduce emissions, improving social welfare. The benefit of lower emissions outweighs the costs of higher deposit volatility, causing the regulator to opt for a positive, albeit smaller ϕ_x as compared to the competitive EELR.

Consumption preference shock. Figure 3 shows the impulse responses following a 0.01 percent positive expansionary consumption preference 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. The nominal interest rate rises as a response to inflation. The consumption rise, coupled with high interest rates, crowds out investment and capital (both types). Therefore, emissions decline. The drop in investment also reduces loan demand. Therefore, both bank deposits and loans drop immediately 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. This changes in the context of the EELR where the dip in emission growth causes the spread between dirty and clean capital lending rates to narrow. In other words, the negative emission growth causes the clean capital lending rate to rise more than the dirty capital lending rate. Banks find the EELR more profitable and increase the supply of clean and dirty capital loans (more so with clean capital loans). This is evident from Figure 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 the competitive EELR, while dirty capital and investment decline by less since dirty capital borrowing is relatively cheaper. Therefore, emissions drop by less with the competitive EELR. Giving banks autonomy in setting the EELR coefficient can have undesirable environmental consequences depending on the nature of the shock.

3.3. Sensitivity analysis

This section examines the sensitivity of the socially optimal EELR to clean capital productive efficiency and households' emission disutility.

Clean capital productive efficiency. The literature on E-DSGE models does not differentiate between the productive efficiency of dirty and clean capital (Punzi, 2018; Annicchiarico et al., 2022; Carattini et al., 2023). Our model adheres to a similar format and assumes A_c in Equation (35) 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 clean tech. 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.

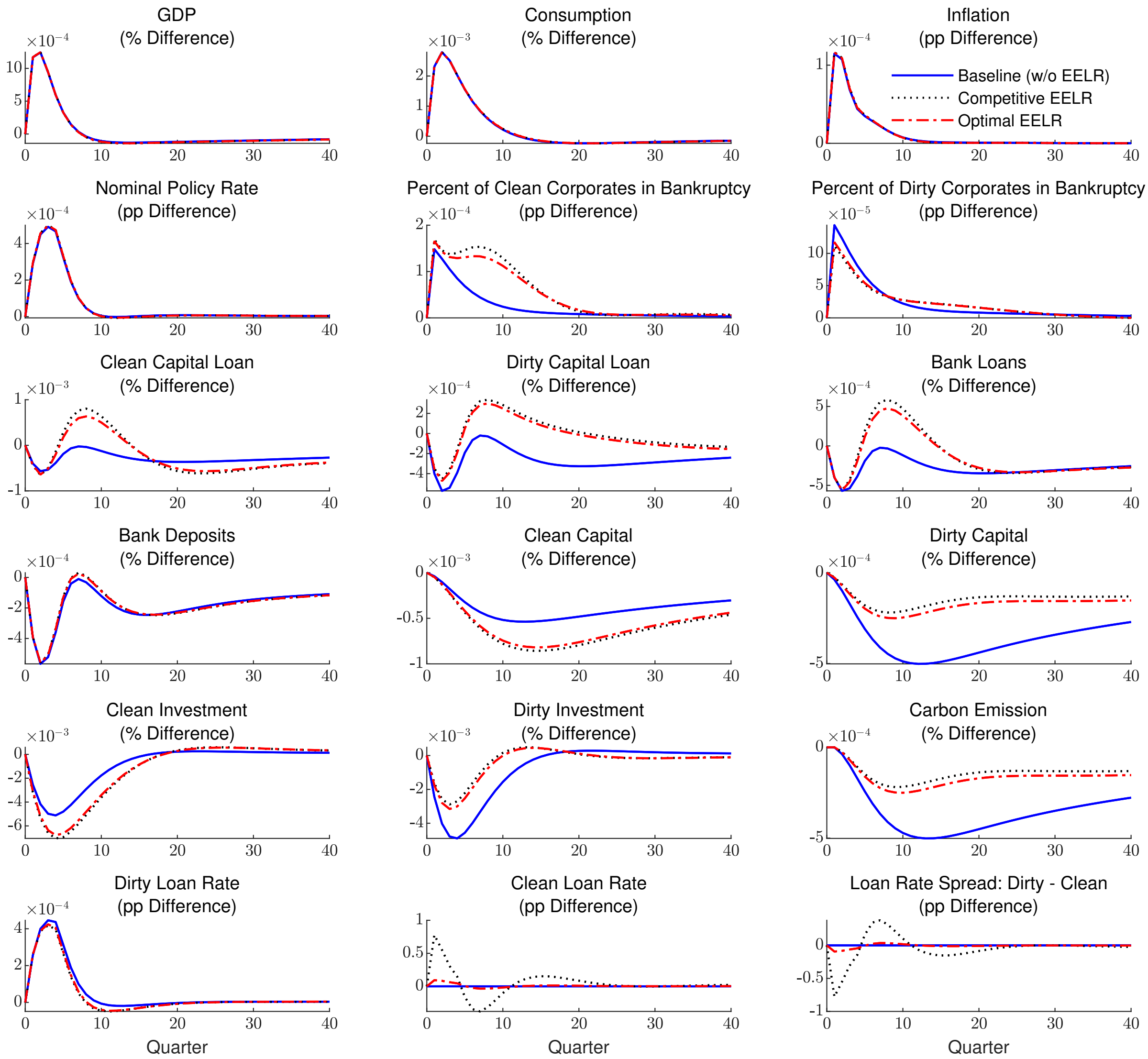

Figure 3: Consumption preference shock

Note: This figure illustrates the impulse responses of key variables following a 0.01 percent positive consumption preference shock.

Panel A of Table 6 shows the steady states of clean and dirty capital for A_c equal 0.5, 1, and 1.5. In the baseline scenario ($A_c = 1$), the steady-state values of both capital types are very close. At 53.29%, clean capital to the total capital ratio in the baseline is relatively lower than reported in Carattini et al. (2023). This changes when A_c equals 0.5, as the dirty capital share is substantially larger than the clean capital share. In contrast, clean capital usage is more than that of dirty capital when A_c equals 1.5. Thus, the productive efficiency parameter A_c has strong implications on the steady states of clean and dirty capital. The clean capital productive efficiency parameter also affects the choices concerning the socially optimal EELR. We conduct similar grid searches as in Section 3 to find the socially optimal EELR ϕ_x for $A_c = 0.5, 1.5$. Panel B of Table 6 reports the results.[14]

The bank profit gain associated with the competitive EELR expands when A_c increases. An increase in clean capital productive efficiency results in the EELR having a larger impact on the demand for

[14]Section 3 report the results pertaining to the benchmark $A_c = 1$. The corner value of $\phi_x = 8$ continues to persist for the competitive EELR irrespective of the level of clean capital productive efficiency. Hence, we showcase only the socially optimal EELR results in the analysis.

Table 6: Implications of clean capital productive efficiency

	$A_c = 0.5$	$A_c = 1$	$A_c = 1.5$
Panel A: Steady states			
Clean capital	8.44	14.68	19.76
Dirty capital	14.80	12.87	11.55
Panel B: Socially optimal EELR			
ϕ_x	4.77	5.89	7.96
Δ welfare	0.0962	0.0957	0.0876
Δ bank profit	0.1048	0.2221	0.3530
Δ σ(emission)	-35.81	-47.30	-56.08
Δ σ(loan)	4.26	7.35	11.02
Δ σ(deposit)	0.21	0.32	0.43

Note: Δ welfare is the consumption equivalent measure with positive values indicating welfare gain as compared to the baseline of no EELR ($\phi_x = 0$). Δ bank profit refers to the percentage change in the mean moments of bank profit compared to the baseline of no EELR ($\phi_x = 0$). Rows with Δ σ report the percentage change in the standard deviation of key variables compared to the baseline. The moments are derived using second-order perturbations around the stochastic steady state in Dynare 5.4 with shocks to technology and consumption preference as specified in Section 2.1.

clean capital loans. As clean lending rises with A_c, bank profit increases. On the contrary, the size of the welfare gain declines when A_c increases. The reason for such an inverse relationship again lies in the deepening of the demand for clean capital loans with a higher A_c. As explained previously in Section 3.2, large movements in clean capital loans increase the instability of aggregate loans, which in turn causes more volatile aggregate deposits. Hence, the EELR can cause more adversity for households when clean capital productive efficiency intensifies. As a result, welfare gain declines with clean capital productive efficiency improvements.

Emissions disutility. The discussions in the previous section reveal that stable emissions drive the social welfare gains associated with the EELR. Hence, modelling the household disutility towards emissions plays an important role in determining the size of the welfare gain with the EELR. In this section, we examine the role that the emission weight parameter in the utility function of the household (μ_x) plays in determining the socially optimal EELR.

We conduct grid searches discussed at the beginning of Section 3 to find the socially optimal EELR coefficient ϕ_x when μ_x varies from 0 to 2. Figure 4 plots the emission disutility weight μ_x on the horizontal axis and the corresponding socially optimal ϕ_x on the vertical axis. The blue line depicts the relationship when both shocks are simultaneously present as per Section 2.1. The black and red lines correspond to the technology and consumption preference shock, respectively.

The key finding from this exercise is that there is a positive relationship between μ_x and the socially optimal EELR ϕ_x, regardless of the shock (shocks) facing the economy. For all values of μ_x, we find a positive ϕ_x, which implies that there are improvements in social welfare when the EELR is implemented.

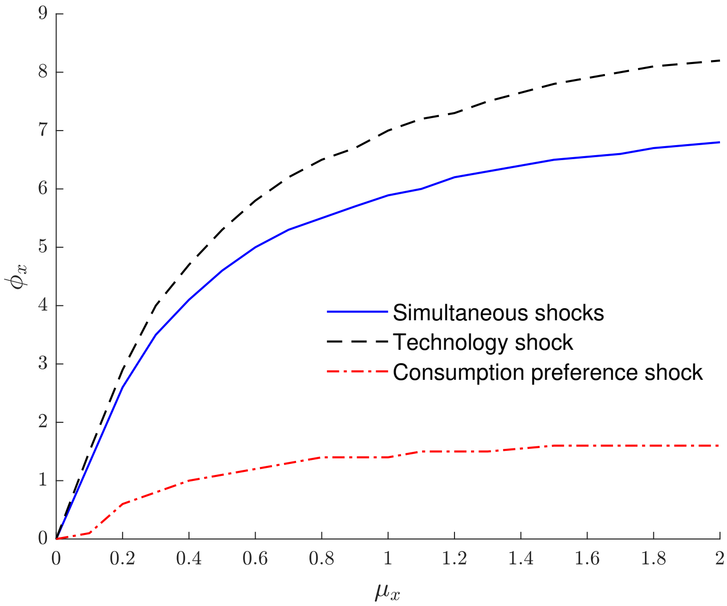

Figure 4: Emissions disutility and the socially optimal EELR

Note: μ_x is the weight of emissions in the utility function and ϕ_x is the corresponding socially optimal EELR.

4. Comparing the socially optimal EELR with GCR

Differentiated capital requirements comprise another popular form of financial market intervention to reallocate financing toward clean capital investments (Dafermos and Nikolaidi, 2021; Oehmke and Opp, 2022; Giovanardi and Kaldorf, 2023). More commonly known as green capital requirements (GCR), this policy tool adjusts the risk weight of clean and dirty loans to either penalise dirty loans or make clean loans more affordable to help economies in their green transition. This section compares the EELR with GCR regarding economic, environmental, and financial stability implications. To make GCR conceptually as close to the EELR as possible, we consider GCR in the form of a green supporting factor wherein the risk weight on clean loans lowers when the emission growth exceeds the target. GCR is modeled by imposing the below rule on the risk weight on clean loan, which makes it time-varying:

$$\Psi_t^c = \overline{\Psi^c} - 100 \times \varphi_x \left(\frac{x_t}{x_{t-1}} - 1 \right) \tag{55}$$

where φ_x is the GCR coefficient. Section 3 results assumed φ_x as zero with bank financing reallocation entirely channelled through the EELR. On the contrary, the GCR regime comprises $\varphi_x > 0$ with the EELR coefficient ϕ_x set as 0. A positive φ_x implies that capital requirements for clean capital loans lower when emission growth exceeds the target. Since clean capital becomes more affordable due to increased clean capital financing, firms substitute dirty capital with clean capital, leading to a drop in emissions.

As in Section 3, we conduct grid searches to derive the socially optimal GCR coefficient φ_x that achieves the highest unconditional mean of $\mathcal{W}_t$ while setting ϕ_x as zero, which results in an optimal value of 0.32 for the GCR coefficient.

4.1. Dynamics

Figure 5 shows the impulse responses of key variables following 0.01 percent positive technology shock in three regimes: a) W/O GCR & EELR ($\phi_x = 0, \varphi_x = 0$), b) GCR ($\phi_x = 0$, $\varphi_x = 0.32$) and c)

EELR ($\phi_x = 5.89$, $\varphi_x = 0$).[15] With a larger drop in clean lending rates, the EELR makes clean loans more affordable than GCR. Consequently, there are larger increases in clean capital and investments associated with the EELR than GCR. The rise in dirty capital is comparatively more muted with the EELR. Hence, the EELR outperforms GCR in reducing emissions. Although the EELR offers more positive environmental outcomes, it is associated with less financial stability, with more volatile deposits and lending.

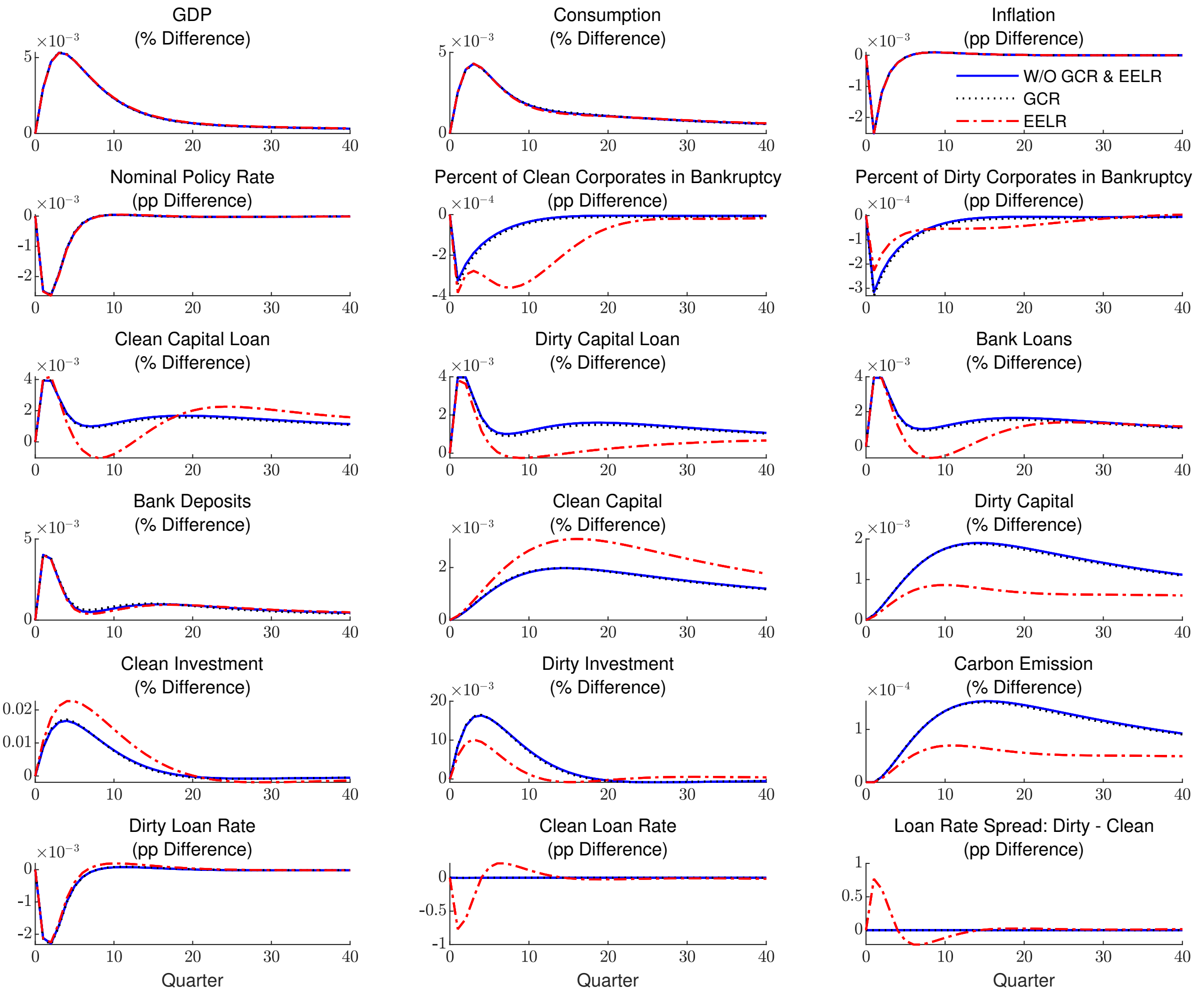

Figure 5: Effects of GCR and EELR

Note: This figure depicts the impulse responses of key variables in response to a positive 0.01 percent technology shock

The financial stability implications are reaffirmed by the results reported in columns (1) - (3) in Table 7, which show the change in moments of the three regimes compared to a benchmark of no policy.[16] Both GCR and the EELR provide better economic and environmental outcomes than the regime without GCR & EELR. Among the three regimes, GCR witnesses more financial stability with relatively more stable deposits. GCR is also accompanied by more economic stability, with the largest decline in consumption and labour volatility. Bank profits decline more with GCR since bank lending regulations are stricter. Households, on the other hand, enjoy welfare gains with GCR on account of

[15] GCR and EELR coefficients equal the socially optimal values. Efficient tax is present in all the regimes showcased in Figure 5. Appendix E shows the impulse responses following the technology shock in the three regimes when the efficient carbon tax is absent.

[16] The no policy benchmark refers to a scenario where there is no climate policy - no carbon tax, no GCR and no EELR($\tau_x = 0$, $\phi_x = 0$ and $\varphi_x = 0$).

economic stability. A comparison between columns (2) and (3) shows that welfare gains are larger with the EELR than GCR due to the more substantial decline in emissions volatility and emissions stock. The EELR is also found to neutralise the impact of the carbon tax on bank profit. The decline in bank profit decreases with the EELR. However, the EELR does not perform well in maintaining macroeconomic and financial stability. Specifically, consumption, labour and deposits are more volatile under the EELR than their counterparts under GCR. In sum, the policy combination of carbon taxes and the EELR delivers a higher welfare than the combination of carbon taxes and GCR, since the former results in a greater reduction in both the stock and volatility of emissions, the benefits of which outweigh the losses from higher financial instability, contributing to greater welfare.

Table 7: Effects of carbon tax, GCR and EELR

	Carbon tax	Carbon tax		No carbon tax	
	w/o GCR & EELR	GCR	EELR	GCR	EELR
	(1)	(2)	(3)	(4)	(5)
Socially optimal					
φ_x	0	0.32	0	0.28	0
ϕ_x	0	0	5.89	0	4.07
Δ welfare	2.7945	2.7950	2.7982	0.0006	0.0039
Δ bank profit	-18.4289	-18.5510	-18.2459	-0.1442	0.0111
Δ emission stock	-6.6030	-6.6037	-6.6112	-0.0009	-0.0063
Δ σ(emission)	-12.6263	-13.6364	-44.9495	-1.0101	-29.2929
Δ σ(consumption)	-0.4832	-0.7997	-0.3041	-0.3499	0.0708
Δ σ(labour)	-0.3152	-0.4853	-0.2050	-0.1897	0.0809
Δ σ(deposit)	0.2920	0.2400	0.6120	-0.0720	0.2480

Note: This table reports the percentage change in the mean and volatility moments associated with incorporating Green capital requirements (GCR) and Emission-elastic lending rates (EELR) in economies with and without carbon tax. The benchmark is a no policy scenario devoid of carbon tax, GCR and EELR. By setting $\phi_x = 0$, GCR columns (2) and (4) report the socially optimal φ_x that maximises $\mathcal{W}_t$ (see eq. (53)). With $\varphi_x = 0$, EELR columns (3) and (5) report socially optimal ϕ_x that maximises $\mathcal{W}_t$. The second and third row panels of the table report the changes in moments as compared to the benchmark. Δ welfare is the consumption equivalent measure with positive values indicating welfare gain. Δ bank profit and Δ emission stock correspond to the percentage change in the mean moments of bank profit and emission stock compared to the benchmark. Rows with Δ σ report the percentage change in the standard deviation of key variables compared to the benchmark. The moments are derived using second-order perturbations around the stochastic steady state in Dynare 5.4 with shocks to technology and consumption preference as specified in Section 2.1.

The results on the EELR and GCR discussed so far are based on the premise that the regulator imposes an efficient carbon tax. Carbon pricing is regarded one of the most powerful tools to help countries limit emissions and reach net-zero targets. Some of the world's biggest emitters have not yet imposed a carbon tax. Scaling up bank financing towards climate goals can be pivotal in curbing greenhouse emissions in such countries. Against this context, we examine the implications of GCR and the EELR in a scenario of no carbon tax ($\tau_x = 0$). Columns (4)-(5) present the results on socially optimal GCR and EELR when the carbon tax policy tool is absent. We find that GCR and the EELR are still effective in lowering emission stock and volatility compared to a benchmark of no policy, resulting in improvements to social welfare. Comparing the two financial market interventions, GCR continue to supersede in terms of better economic and financial stability implications, while the EELR is more effective in lowering the emission stock and volatility.

A comparison of results from columns (1)-(5) shows that the EELR and GCR are complements for the carbon tax instead of substitutes. Carbon tax without GCR & EELR (see column (1)) yields far better welfare, environmental and macroeconomic outcomes than no carbon tax GCR/EELR (see columns (4)-(5)). Thus, neither GCR nor EELR can replace the carbon tax as a policy tool. That said, climate financing market interventions accompanied by carbon tax do present a more ideal climate policy cocktail than the carbon tax alone. A combination of the EELR and efficient carbon tax (see column (3)) is the best-performing policy scenario with the most significant improvements in social welfare and emission outcomes.

4.2. Green transition risk with carbon tax: EELR vis-a-viz GCR

In this section, we consider the unexpected introduction of the efficient carbon tax at 27 dollars per ton of CO2 to an economy that did not impose a carbon tax earlier. This context could be considered as a sudden shift in climate policy for countries that have so far had insufficient climate action. Following the introduction of such a permanent tax shock, we compare the transitional dynamics to a low-carbon-emission economy between frameworks with and without climate financing intervention frameworks.

Figure 6 shows the transitional dynamics following the unexpected introduction of the permanent carbon tax in quarter 1. The economy starts at the baseline deterministic steady state of no carbon tax ($\tau_x = 0$). The dashed grey line shows the long-run change in the steady states after the permanent carbon tax implementation. The blue solid line shows the transitional dynamics when both GCR and the EELR are absent. The rise in the price of emissions due to the introduction of the carbon tax makes dirty capital more expensive, driving firms to reallocate from dirty to clean capital and to increase their abatement efforts, causing emissions to decline with the economy moving to a low-carbon emission steady state. However, the green transition accompanies an economic downturn risk, as the drop in dirty capital exceeds the rise in clean capital. Consequently, the aggregate capital stock decreases, leading to a fall in GDP.

The dashed black and red lines show the transition to the low-carbon emission steady state in the presence of GCR and the EELR, respectively. With GCR, the decrease in emissions increases the capital requirement for clean loans, leading to lower clean capital loan issuance. Therefore, clean capital and investment rise by less under GCR, leading to a larger drop in aggregate capital. Hence, GCR can witness a larger drop in GDP.

The EELR presents different results as compared to GCR. The drop in emissions makes clean capital lending more expensive than dirty lending. Hence, clean capital rises by less as compared to the baseline. However, banks find the EELR profitable and increase the issuance of bank loans. The expansion in lending translates to a relatively smaller contraction of dirty capital. With smoother capital reallocation dynamics, aggregate capital and GDP drops by less with the EELR. Thus, the EELR reduces the green transition risk associated with the introduction of a permanent increase in carbon tax.

Although the EELR presents the possibility of a lower risk of green transition, it is associated with more distortions in the banking sector than GCR. This is evident from the drastic increases in lending and deposits in the presence of the EELR.

5. Conclusion

This paper develops a two-sector New Keynesian DSGE model with a full-fledged banking sector following Benes and Kumhof (2015) where capital investment agencies borrow from banks to finance capital purchases. Commercial banks differentiate lending rates between clean and dirty capital investment agencies using the emission-elastic lending rate (EELR). When emission growth exceeds the target, banks lower the lending rates to clean capital investment agencies, 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 the EELR beyond emission abatement. We find that the EELR 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 the EELR increase

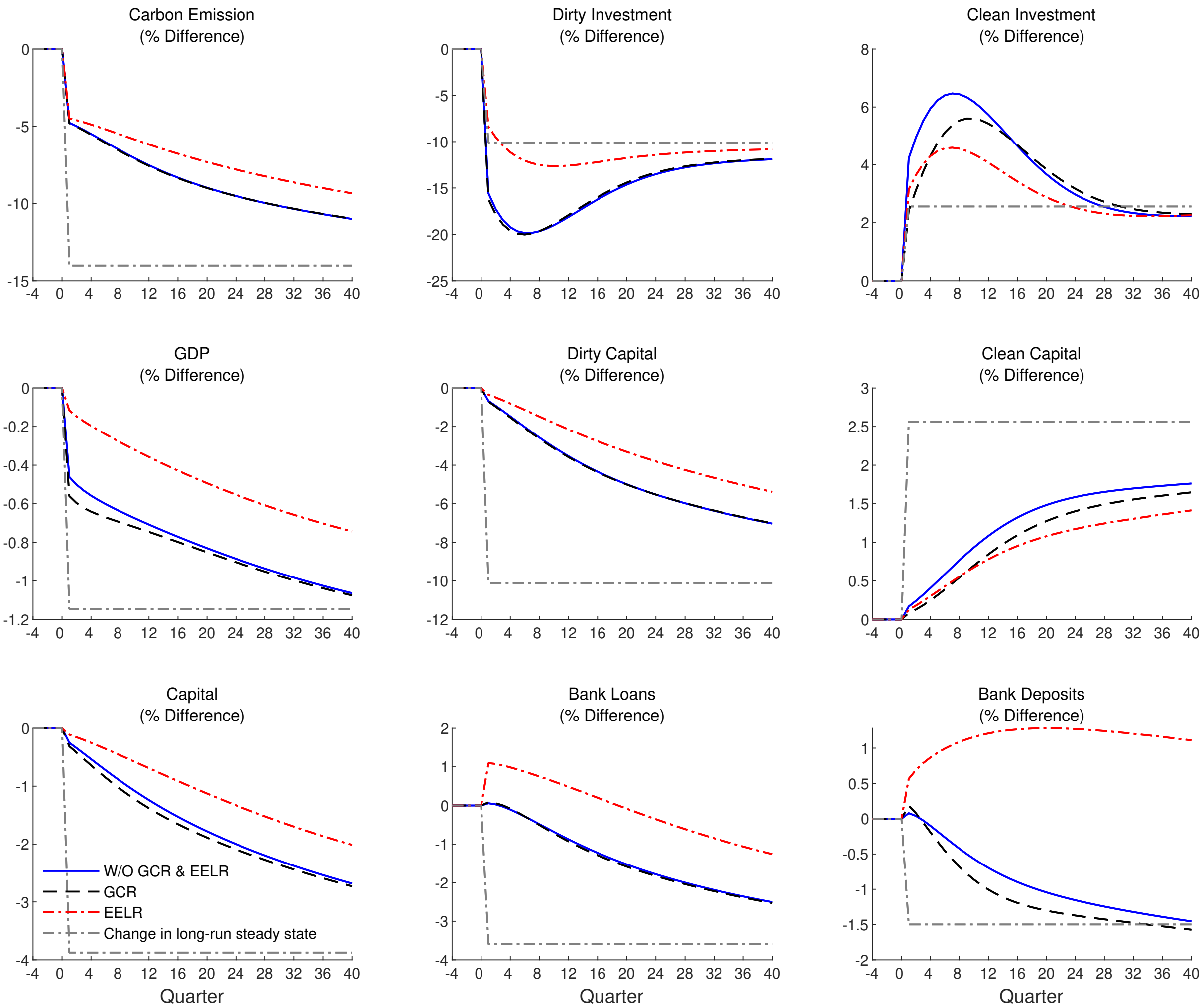

Figure 6: Green transition risk with GCR and EELR.

Note: This figure shows the transition dynamics in response to an unanticipated introduction of the permanent carbon tax of about 27 dollars per ton of CO2.

financial sector uncertainty, adversely affecting social welfare. Furthermore, this paper compares the EELR and green capital requirements (GCR) in scenarios both with and without a carbon tax policy. Our analysis demonstrates that the EELR and GCR complement carbon taxes rather than acting as substitutes for such policies. Moreover, we find that while the EELR holds the promise of facilitating a smoother transition toward green investments, it also introduces more distortions in the banking sector when compared to GCR.

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Online Appendix

Appendix A. FOC for banks' optimization problem

First we define a auxiliary variable:

$$\sqcap_t = \frac{\chi \mathfrak{f}_t^b(\bar{\omega}_{t+1}^b)\left(\frac{l_t}{\mathsf{n}_t^b}\right)}{\sum_{j=c,d}\left[(1-\Psi^j\gamma_t)\frac{\tilde{r}_{jt+1}^l l_{jt+1}}{\mathsf{n}_t^b}\right]^2}$$

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

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

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

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

Appendix B. Elasticity of substitution between clean and dirty capital

We examine the effects of the elasticity of substitution between clean and dirty capital on the socially optimal EELR. The elasticity of substitution parameter φ equals 2 in our baseline. In this exercise, we compare the implications of low, baseline and high elasticity of substitution at $\varphi = 1.5, 2, 4$, respectively. Table B.1 reports the socially optimal EELR ϕ_x at each values of φ. The socially optimal EELR coefficient and the associated welfare gains decline when the value of φ increases. With clean and dirty capital easily substitutable, the loan demand dynamics will be even stronger with EELR. The table shows that loan volatility increases with EELR. As a consequence, bank profit gains are also larger when φ increases. The concomitant rise in financial instability results in welfare gains associated with socially optimal EELR to narrow when φ increases.

Table B.1: Implications of elasticity of substitution between clean and dirty capital

	$\varphi = 4$	$\varphi = 2$	$\varphi = 1.5$
Socially optimal EELR			
ϕ_x	1.29	5.89	8
Δ welfare	0.0416	0.0957	0.1635
Δ bank profit	0.3077	0.2755	0.2688
σ(loan)	0.2246	0.2174	0.2147

Note: φ is the elasticity of substitution between clean and dirty capital. Δ welfare is the consumption equivalent measure with positive values indicating welfare gain as compared to the benchmark of no EELR ($\phi_x = 0$). Δ bank profit refers to the percentage change in the mean moments of bank profit compared to benchmark of no EELR ($\phi_x = 0$). Rows with σ(deposit) report the standard deviation of aggregate loans. The moments are derived using second-order perturbations around the stochastic steady state in Dynare 5.4 with shocks to technology and consumption preference as specified in Section 2.1.

Appendix C. Variance decomposition

Table C.1: Variance decomposition (%)

	Technology shock	Consumption preference shock
GDP	86.30	13.70
Consumption	52.98	47.02
Investment	89.09	19.01
Inflation	99.45	0.55
Policy rate	93.94	6.06

Appendix D. Other figures in welfare analysis

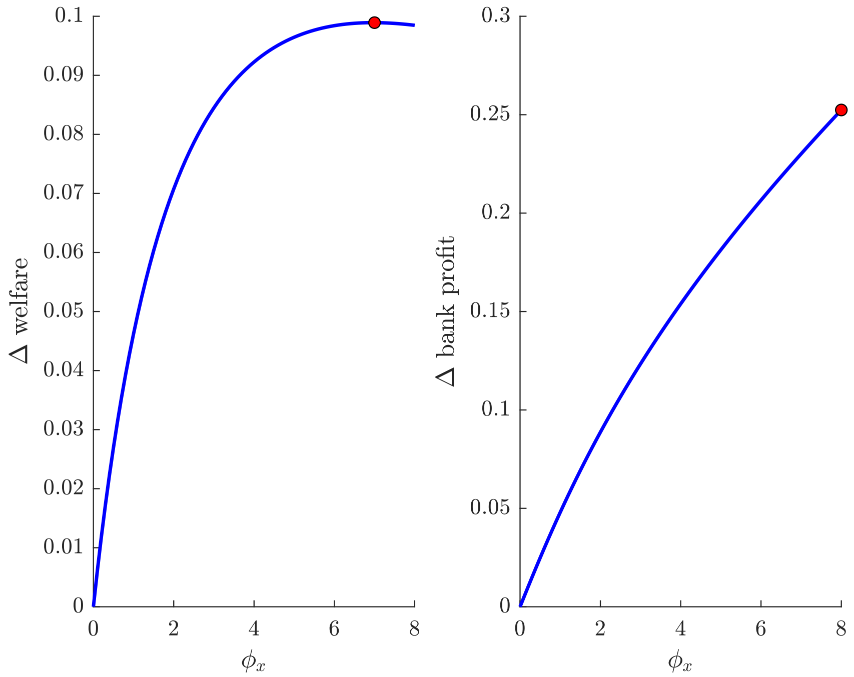

Figure D.7: Welfare gain and bank profit with EELR: Technology shock

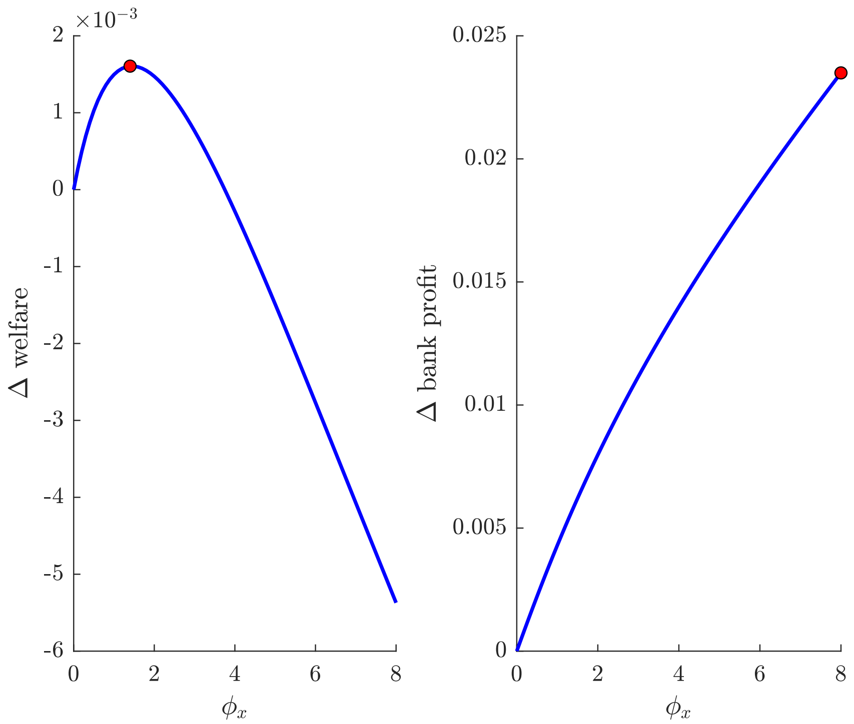

Figure D.8: Welfare gain and bank profit with EELR: Consumption preference shock

Appendix E. Dynamics with GCR and EELR

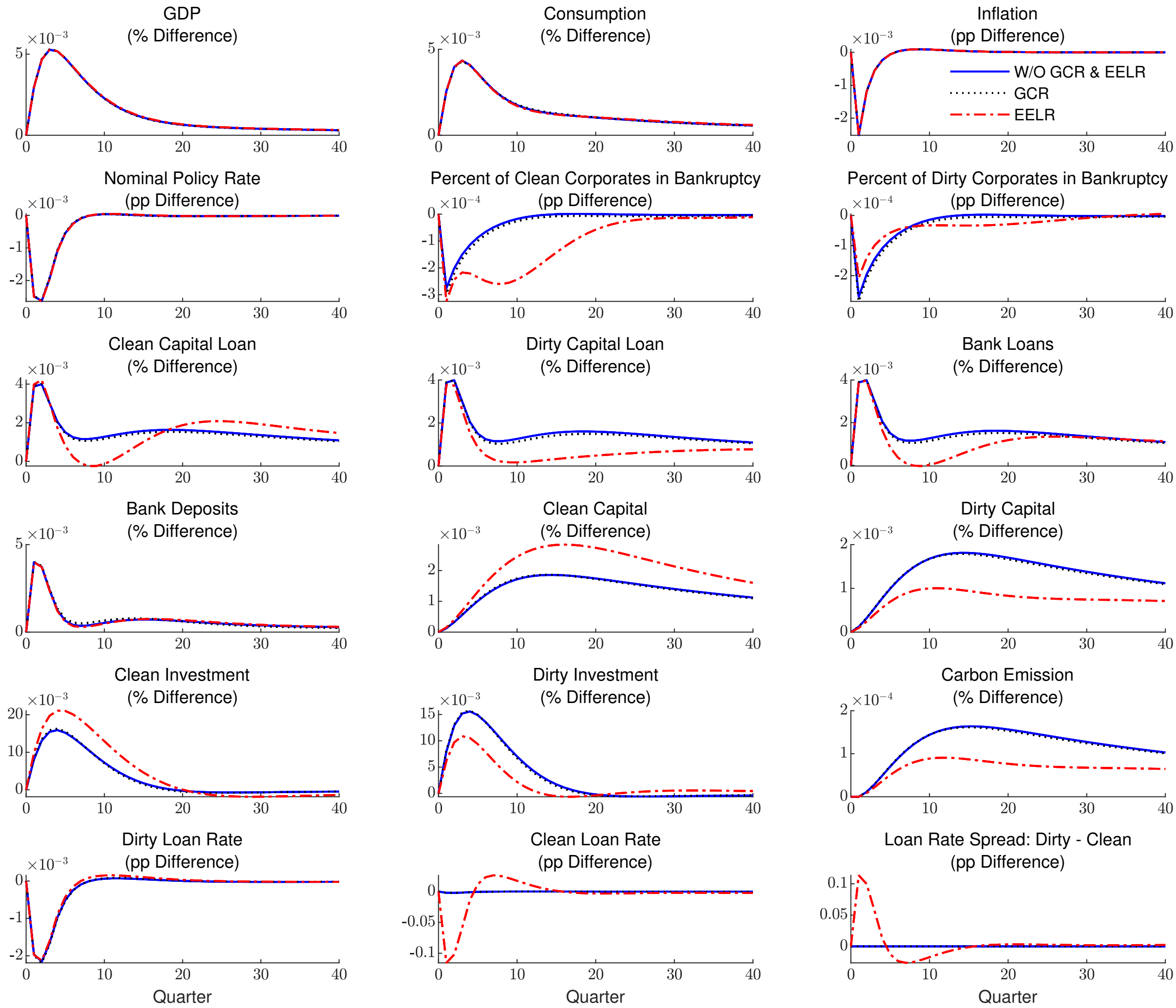

Figure E.9: Technology shock without carbon tax policy tool

Note: This figure illustrates the impulse responses of key variables following a 0.01 percent positive technology shock. All the regimes have no carbon tax policy ($\tau_t^x = 0$).