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## The preferential treatment of green bonds

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# **The Preferential Treatment of Green Bonds**

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June 2021

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# The Preferential Treatment of Green Bonds <sup>\*</sup>

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## Abstract

We study the preferential treatment of green bonds in the Central Bank collateral framework as an environmental policy instrument. We propose a macroeconomic model with environmental and financial frictions, in which green and conventional entrepreneurs issue defaultable bonds to banks that use them as collateral. Collateral policy solves a financial stability trade-off between increasing bond issuance and subsidizing entrepreneur default risk. In a calibration to the Euro Area, optimal collateral policy features substantial preferential treatment, implying a green-conventional bond spread of 73bp. This increases the green bond share by 0.69 percentage points, while the green capital share increases by 0.32 percentage points, which in turn reduces pollution. The limited response of green investment is caused by higher risk taking of green entrepreneurs. When optimal Pigouvian taxation is available, collateral policy does not feature preferential treatment, but still improves welfare by addressing adverse effects of taxation on financial stability.

*Keywords:* Green Investment, Central Bank Policy, Collateral Framework, Corporate Default Risk, Environmental Policy

*JEL Classification:* E44, E58, E63, Q58

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# 1 Introduction

The European Central Bank (ECB) publicly contemplates taking a more active role in environmental policy within its ongoing strategy review. In particular, the ECB floated the idea of treating green bonds preferentially in its collateral framework, i.e. the conditions under which banks can pledge assets to obtain short-term funding from the Central Bank.<sup>1</sup> The People's Bank of China (PBoC) started accepting green bonds as collateral on preferential terms already in 2018. However, there is limited knowledge about the impact of preferential collateral treatment on green investment, its potential adverse side effects, and its interaction with fiscal policy.

Our paper fills this gap by proposing a macroeconomic model of collateral policy with and environmental externality and financial frictions. The transmission of collateral policy operates through banks, which increase demand for bonds that are eligible as collateral. Non-financial corporations respond to an increase in bond demand by increasing their debt issuance, investment, and risk-taking. Tilting the collateral framework in favor of green bonds increases banks' demand for such bonds. This increases the shares of green bonds and capital in equilibrium, resulting in a decrease of pollution.

However, this policy has adverse side effects: by affecting risk-taking and dividend policies of non-financial firms, the transmission of preferential treatment to green investment is severely impaired. Indeed, our results suggest that a sizable share of newly issued green bonds does not transmit to investment in green technologies. In contrast, when we introduce Pigouvian taxation by a fiscal authority, the share of green capital can be raised substantially *without* adverse effects on risk-taking. This result should not be misinterpreted as call for Central Bank inaction. Since optimal Pigouvian taxation depresses overall economic activity, it reduces aggregate collateral supply to an inefficiently low level. The Central Bank optimally addresses this by relaxing its collateral policy, thereby ensuring collateral supply stays optimal. However, collateral policy does not involve preferential treatment in this case. In contrast, if fiscal policy is restricted in its ability to set taxes optimally, for example due to political economy frictions, the Central Bank can increase welfare by tilting the collateral framework towards green bonds. The extent of preferential treatment monotonically declines, the closer Pigouvian taxation gets to its optimal level.

We model the transmission of preferential treatment, its adverse side effects, and its interplay with financial stability and fiscal policy in an extended New-Keynesian DSGE model. We introduce a role for environmental policy by assuming that there are two types of entrepreneurs, green and conventional. Conventional entrepreneurs generate a negative externality (pollution) during the production of intermediate goods, while green entrepreneurs have access to a clean

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<sup>1</sup>Such a policy was also proposed in Brunnermeier and Landau (2020).

production technology. Following Heutel (2012) and Golosov et al. (2014), pollution negatively affects final good production, implying sub-optimal under-investment into the green technology under laissez-faire.

Studying preferential collateral treatment also requires modelling the corporate bond market, since it ultimately links collateral policy to the real sector. We achieve this by assuming that entrepreneurs are more impatient than households and issue defaultable long-term bonds to banks which can use them to collateralize short-term borrowing. Following the ability-to-repay approach, entrepreneurs default on their bonds if revenues from production fall short of current repayment obligations. Their borrowing is thus determined by a trade-off between relative impatience, an incentive to front-load consumption, and bankruptcy costs, which reduce expected future consumption, similar to Gomes et al. (2016).<sup>2</sup>

Collateral policy is linked to entrepreneur's financing and investment decisions by assuming that banks need to settle liquidity deficits in a costly manner. Specifically, these costs are decreasing in the amount of available collateral, following Piazzesi and Schneider (2018). This introduces a willingness of banks to pay *collateral premia* on corporate bonds.<sup>3</sup> Entrepreneurs respond to collateral premia by increasing their leverage, bond issuance, and investment. However, elevated leverage also implies higher default rates, such that collateral policy is determined by a financial stability trade-off between incentivizing entrepreneur default risk and increasing collateral supply.

The link between entrepreneurs and collateral policy via banks' demand for bonds allows the Central Bank to affect the relative prices of green and conventional bonds by tilting the collateral framework in favour of green bonds.<sup>4</sup> *Ceteris paribus*, banks are willing to pay higher prices on green bonds relative to conventional bonds, since they can be used more easily to settle liquidity deficits. Preferential treatment increases bond issuance and investment of green entrepreneurs, while conventional entrepreneurs reduce their bond and investment position. Higher default risk reduces the expected return to green investment, such that the equilibrium green investment share is smaller than the green bond share under such a policy. As a result, the transmission of preferential treatment on the green investment share is substantially dampened.<sup>5</sup> Notably, the effect on the green investment share is *permanent*, i.e. Central Bank

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<sup>2</sup>Since our focus is on the collateral framework, we employ a financial friction that restricts leverage rather than external financing as in the canonical financial accelerator model of Bernanke et al. (1999).

<sup>3</sup>Collateral premia on corporate bonds have been documented by Mésonnier et al. (2020), Pelizzon et al. (2020), and Mota (2020). Kaldorf and Wicknig (2021) provide a structural analysis of collateral premia and corporate default risk.

<sup>4</sup>Preferential treatment can take the form of relaxed eligibility requirements, reduced haircuts on eligible green bonds, or a combination of both. We omit this layer of complexity, since banks increase demand for green bonds in both cases.

<sup>5</sup>This is in line with the literature on eligibility premia. Bekkum et al. (2018) observe a decrease in repayment performance on the mortgage backed securities market following eligibility, which indicates adverse side effects of relaxing collateral standards. Using French data, Harpedanne de Belleville (2019) finds a sizeable increase in

collateral policy is *not neutral* even in the long run.<sup>6</sup> The Central Bank thus faces a trade-off between decreasing the production externality and deviating from the collateral level solving the financial stability trade-off.

To quantify the effects of preferential treatment, we calibrate the model to Euro Area data and conduct a number of policy experiments. First, we study a simple preferential policy, which leaves the treatment of conventional bonds unaltered. This policy induces a green-conventional bond spread (also referred to as *greenium*) of 48bp in equilibrium which translates into a change in the relative share of green bonds from 20% to 20.45% while the share of green capital only increases from 20% to 20.21%. However, simple preferential treatment is not optimal from a financial stability perspective, since it increases collateral supply above its optimal level. Therefore, we also maximize the welfare objective over the entire policy space and find that optimal collateral policy tightens the treatment of conventional bonds to counter the adverse effects of high aggregate collateral supply under simple preferential treatment. In this case, the greenium widens to 73bp, the relative share of green bonds goes up to 20.69%, while the share of green capital increases to 20.32%.

The greenium implied by our policy experiments is in line with Macaire and Naef (2021), who study the yield reaction of green bonds after the PBoC implemented preferential treatment and find an average yield reaction of 46 basis points. To further corroborate the plausibility of our policy experiments, we obtain data on the European market for green bonds and study their yield reaction around ECB policy announcements regarding its environmental policy in general, and preferential treatment of green bonds in particular. Identifying five such announcements, we find a significant yield reduction of 9 basis points in the month following the announcement, relative to a matched control group of conventional bonds. To compare these announcement effect to our model, we interpret the announcement of preferential treatment as a news shock (Beaudry and Portier, 2004; Barsky and Sims, 2011). Since the ECB did not announce a specific date so far, we consider various time horizons and find a model implied yield reduction of 11bp, if preferential treatment applies after three years.

While our numerical findings suggest that collateral frameworks can initiate a shift towards green technologies, this shift is small and accompanied by adverse side effects. However, considering a setup in which fiscal policy can implement Pigouvian taxes on conventional production or subsidies on green production, we find that there is still scope for active Central Bank policy. We model fiscal policy as a time-invariant subsidy on green production that is entirely

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investment by issuers of newly eligible bonds following a reduction of collateral requirements in February 2012. Upward adjustments of dividend policy have been documented for issuers of QE-eligible bonds by Todorov (2020). The transmission of this policy could be more effective, if the Central Bank was able to condition preferential treatment on investment covenants or dividend caps.

<sup>6</sup>Asset purchase programmes have an anti-cyclical component by design and, therefore, seem less well suited in an environmental policy context, which by definition addresses long-run problems.

financed by a tax on conventional goods. When the Central Bank keeps the collateral framework at its baseline value, the optimal Pigouvian tax on conventional production is 7%. Such a policy increases the share of green capital by 5.6 percentage points and substantially reduces the pollution externality. In consumption equivalents, this increases welfare by 0.7% while optimal collateral policy without Pigouvian taxation only increases welfare by 0.05%. At the same time, taxation does not affect the risk-choice of entrepreneurs, such that the transmission to green investment shares is not impaired.

However, Pigouvian taxation also has a financial stability impact: by shrinking the size of the conventional production sector, it reduces the amount of available collateral. Therefore, in a fully-optimal set-up, the Central Bank relaxes collateral treatment to restore the financial stability trade-off.<sup>7</sup> Notably, the optimal policy mix does not imply preferential treatment: it is more lenient in a symmetric fashion. By countering the adverse effect of environmental (fiscal) policy on collateral supply, the Central Bank can improve welfare. Put differently, collateral policy addresses second round effects of Pigouvian taxation. We stress that this symmetry result only holds if the fiscal authority is able to implement the optimal Pigouvian tax. Whenever fiscal policy is constrained in implementing the optimal tax rate, for example due to political economy frictions, the Central Bank optimally uses preferential treatment to support the shift toward green technologies.

As a by-product of our analysis, we show that nominal rigidities are not an important driver of our central results. To do so, we repeat our policy experiments (1) without nominal rigidities and (2) with an arbitrarily large parameter on inflation in the Taylor rule, mimicking the behavior of a Central Bank that closes the output gap in every period. The implications for optimal Pigouvian taxation and optimal collateral policy are hardly affected in both cases. This suggests that environmental policy in general and the preferential treatment of green bonds in particular do not interfere with the price stability objective of the Central Bank. To certain extent, these results hinge on the fact that price stability is a concern for business-cycle frequencies, while effective environmental policies ultimately affect the steady state, leaving the short-run dynamics of the economy unaltered.

**Related Literature.** There is a small but fast growing literature that adds environmental aspects to DSGE models suitable for Central Bank policy analysis at business cycle frequencies, such as Heutel (2012). The first paper to explicitly add nominal rigidities into this setting is Annicchiarico and Di Dio (2016), who study the interaction of monetary policy operating through the interest rate channel with environmental policy. Punzi (2019) extends this setup by adding

<sup>7</sup>This feature is similar to Carattini et al. (2021), who show that macroprudential policy can alleviate adverse effects of carbon taxation in the presence of transition risk. In their model, adverse effects take the form of asset stranding, while in our case adverse effects are linked to collateral scarcity, if conventional firms reduce their bond issuance.

financial intermediation of loans to the credit-constrained corporate sector to study green credit policy. This sets her paper apart from ours, since credit policy tools are typically not part of the Central Bank toolkit.

Some papers explicitly discuss Central Bank environmental action. Papoutsis et al. (2021) show how Central Banks can tilt their asset purchases towards green assets to address environmental frictions. However, they assume that Central Banks are able to buy firm equity and are silent about the pass-through via the corporate bond market which is generating a limited policy transmission in our model. For a specific assessment of green QE, see Ferrari and Nispi Landi (2020), who find a modestly positive impact on aggregate environmental performance. Böser and Senni (2020) study the effects of making refinancing conditions of banks dependent on the carbon footprint of their assets. While the idea of affecting the capital allocation indirectly via banks is similar to our framework, implementing such a policy requires considerable regulatory and supervisory effort, since bank balance sheets in practice are often opaque. Indeed, such a policy might incentivize banks to hide their carbon exposure in off-balance sheet investment vehicles or engage in other forms of regulatory arbitrage. While we acknowledge that the taxonomy of green bonds is not free of problems as well, these are already being addressed. We then view preferential collateral treatment of green bonds a much more practical policy. Fender et al. (2019) evaluate to which extent green assets can be included in managing the foreign reserve holdings of Central Banks. They find that green bonds are similar in terms of safety and returns to conventional ones but are usually less liquid. Hong et al. (2021) study sustainable investment mandates, which have a similar transmission mechanism on firm investment operating through asset demand by financial intermediaries. In their setup, sustainable investment mandates, in the form of minimum portfolio shares, increase welfare, since they widen the cost of capital wedge between green and conventional firms.

We abstract from an analysis of transition risk, which arises if demand for conventional goods suddenly decreases due to ambitious environmental policy. Carattini et al. (2021) argue that macroprudential policies can address this issue. See also Diluiso et al. (2020) on green credit policy and Catalano et al. (2020) on fiscal policy in the context of transition risk.

In all these papers, pollution externalities are assumed to negatively affect total factor productivity. The policy implications drawn from these models may not hold when environmental risk affects financial and macroeconomic stability in different ways. Giglio et al. (2020) and Hong et al. (2020) provide a review of the literature studying the effect of climate risk on other dimensions of financial and macroeconomic stability. Adding these dimensions promises richer policy trade-offs, but is beyond the scope of our paper.

**Outline.** The paper is structured as follows. We introduce our structural model in section 2, while section 3 contains our calibration. Our policy analysis is discussed in section 4. In



section 5, we benchmark the policy implications from our model against the effect of ECB announcements on green bond spreads. Section 6 concludes.

## 2 Model

Time is discrete and indexed by  $t = 1, 2, \dots$  and each period is divided into two sub-periods. The model features a representative *household*, two types of intermediate goods producers (*entrepreneurs*), a perfectly competitive *wholesale firm*, aggregating both types of intermediate goods into a composite intermediate good, monopolistically competitive *final good producers*, financial intermediaries (*banks*), and a public sector consisting of a fiscal authority and the Central Bank. Entrepreneur types are indexed by  $\tau \in \{c, g\}$ . One type of intermediate goods producers (the *conventional entrepreneur*) causes an externality when producing intermediate goods. The technology of the *green entrepreneur* does not cause the externality. Both types of intermediate goods are aggregated into a composite intermediate good by a perfectly competitive wholesale firm. Monopolistically competitive final goods producers use the composite intermediate good and labor to produce a differentiated consumption good which they sell to the household. They face quadratic price adjustment costs giving rise to a New Keynesian Phillips curve. Banks raise deposits from the household to invest into corporate bonds and settle their liquidity deficits by borrowing short-term in the second sub-period. Specifically, the Central Bank sets the nominal (deposit) rate and the collateral framework. The structure of the model is summarized in Figure 1.

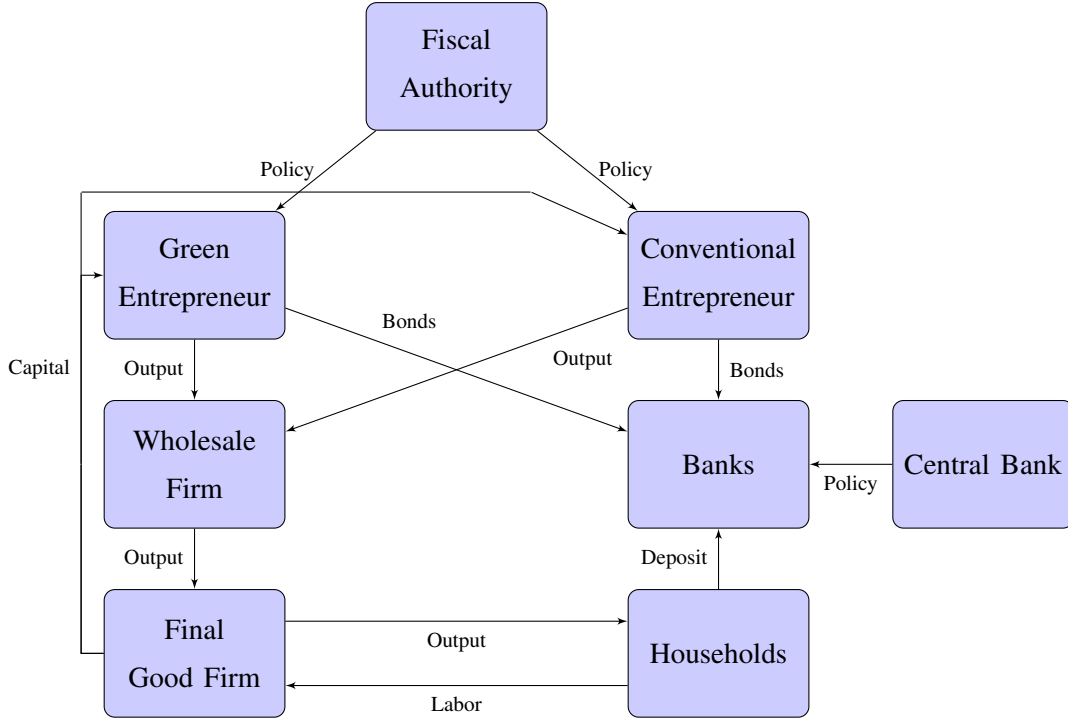


Figure 1: Model Structure

**Timing.** The sub-periods differ with respect to which markets are active: at the beginning of sub-period 1, all shocks realize and the Central Bank sets its policy with commitment throughout the entire period. Households, firms, and banks make their investment and savings decisions. In sub-period 2, only banks are active. They face a liquidity deficit which can only be settled using short-term borrowing against collateral. The timing of events within a period is summarized in Figure 2.

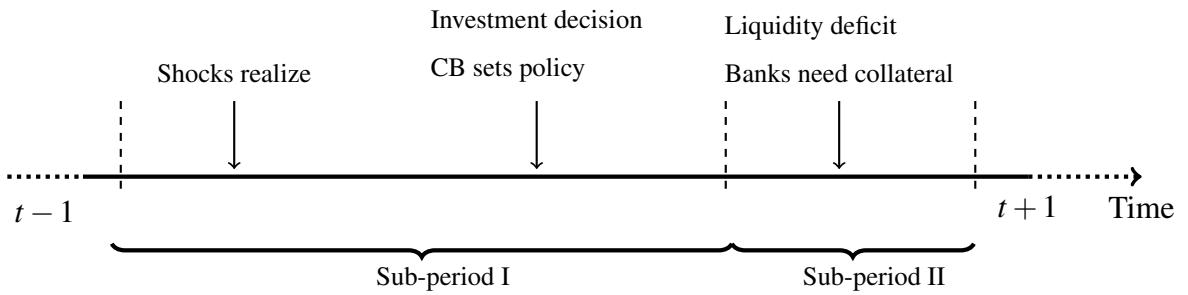


Figure 2: Timing Assumption

## 2.1 Households

There is a representative household that enjoys utility from a constant elasticity of substitution consumption bundle of the final good varieties,  $c_{i,t}$ , and suffers disutility from supplying labor,

$l_t$  at nominal wage rate  $W_t$ . The final goods basket  $c_t$  is given by

$$c_t = \left( \int_0^1 c_{i,t}^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}},$$

where  $\varepsilon > 1$  is the elasticity of substitution among the differentiated final goods. The demand schedule for final good  $i$  is given by

$$c_{i,t} = \left( \frac{P_{i,t}}{P_t} \right)^{-\varepsilon} c_t, \quad (1)$$

where  $P_t$  denotes the CES price index for final consumption bundle. To transfer resources across time, the household has access to nominal deposits  $D_t$ . Deposits held from time  $t-1$  to time  $t$  earn a pre-determined nominal interest rate  $i_{t-1}^D$ . The discount factor is denoted by  $\beta$ ,  $\omega_L$  is the weight on utility-weighted labor, and  $\gamma_C$  and  $\gamma_L$  are the inverse of intertemporal elasticity of substitution and the inverse of Frisch elasticity of labor supply, respectively. The maximization problem of the representative household is given by

$$\begin{aligned} V(d_t) = & \max_{c_t, l_t, d_{t+1}} \frac{c_t^{1-\gamma_C}}{1-\gamma_C} - \omega_L \cdot \frac{l_t^{1+\gamma_L}}{1+\gamma_L} + \beta \mathbb{E}_t [V(d_{t+1})], \\ \text{s.t. } & c_t + d_{t+1} = w_t l_t + (1 + i_{t-1}^D) \frac{d_t}{\pi_t} + \Pi_t, \end{aligned} \quad (2)$$

where the budget constraint is written in real terms using the final consumption bundle as numeraire. Gross inflation is denoted by  $\pi_t$ ,  $w_t = \frac{W_t}{P_t}$  denotes the real wage rate, and  $\Pi_t$  collects (real) profits from banks and final goods producers. First-order conditions with respect to labor and consumption yield standard inter- and intratemporal optimality conditions

$$c_t^{-\gamma_C} = \beta \mathbb{E}_t \left[ \frac{(1 + i_t^D) c_{t+1}^{-\gamma_C}}{\pi_{t+1}} \right], \quad (3)$$

$$w_t = \frac{\omega_L l_t^{\gamma_L}}{c_t^{-\gamma_C}}. \quad (4)$$

## 2.2 Banks

There is a unit mass of perfectly competitive banks that supply deposits to households and invest into corporate bonds. They participate in asset markets sequentially: in the first sub-period, banks trade with households on the deposit market and with entrepreneurs on the bond market. In the second sub-period, banks face a liquidity deficit which they settle on a collateralized short-term funding market. We solve the bank problem by backward induction.

**Banks in Sub-Period 2.** Banks enter second sub-period with a fixed corporate bond portfolio, determined in the first sub-period, and face a liquidity deficit  $\omega$ , which has to be settled immediately. Since no trade with other private agents is possible, deficits have to be settled using short-term funding, either from other banks or from the Central Bank. We assume that settlement is costly, and that these costs can be represented by  $\omega \cdot \Omega(\bar{b}_{t+1}^i, \bar{F}_{t+1})$ , with the per-unit costs satisfying  $\Omega_{b,t} \equiv \frac{\partial \Omega}{\partial \bar{b}_{t+1}^i} < 0$  and  $\Omega_{F,t} \equiv \frac{\partial \Omega}{\partial \bar{F}} > 0$ . The first assumption on  $\Omega$  implies that per-unit costs negatively depend on aggregate collateral held by bank  $i$

$$\bar{b}_{t+1}^i = \phi_c q_{c,t} b_{c,t+1}^i + \phi_g q_{g,t} b_{g,t+1}^i, \quad (5)$$

which is given by the market value of bonds  $q_{\tau,t} b_{\tau,t+1}^i$ , weighted with the collateral parameters  $(\phi_c, \phi_g)$ .<sup>8</sup> Banks directly benefit from a relaxation in collateral policy, since this increases available collateral  $\bar{b}_{t+1}$  ceteris paribus. While liquidity management costs decrease in collateral supply, they are also assumed to depend positively on the aggregate default risk of the banking sector's assets

$$\bar{F}_t \equiv \sum_{\tau} \frac{b_{\tau,t}}{b_{c,t} + b_{g,t}} F(\bar{m}_{\tau,t}), \quad (6)$$

where  $F(\bar{m}_{\tau,t})$  is the probability of default of the type- $\tau$  entrepreneur.

The assumption  $\Omega_{b,t} < 0$  captures in reduced form the benefits of collateral to settle idiosyncratic liquidity shocks on interbank markets or with the central bank. Since neither the sources of liquidity demand, which might be heterogeneous deposit and credit line withdrawals or market making activity, nor the reason why this market is collateralized are at the heart of our paper, we introduce this feature in reduced form and refer to Corradin et al. (2017), De Fiore et al. (2019), Bianchi and Bigio (2020), and the references therein for more details and different micro-foundations.

The positive dependency of per-unit costs on default risk  $\Omega_{F,t} > 0$  reflects the notion that intermediating risky assets and safe deposits is socially costly, which is a recurring theme in the banking literature. Goldstein and Pauzner (2005) propose a model in which bad fundamentals of bank assets increase the probability of a bank run. At the same time, the term  $\bar{F}$  does not enter bank first-order conditions, since financial stability only depends on *aggregate* default risk in the banking sector. Consequently, bank funding costs are independent of the riskiness of bank assets and default risk. In practice, this can follow from banks exerting market power over depositors (Drechsler et al., 2017), deposit insurance (Diamond and Dybvig, 1983), or

<sup>8</sup>In the calibration and our main policy experiments, we restrict the analysis to time-invariant collateral parameters. While collateral frameworks in practice are occasionally adjusted, this usually happens in response to large shocks to the financial systems. These events are not of first-order importance for an analysis of preferential treatment.

information insensitivity of bank deposits. For the canonical model, we refer to Diamond (1984). Kacperczyk et al. (2020) lend empirical support by showing that bank funding costs do not depend on idiosyncratic risk of bank assets. Instead funding costs react if the overall solvency of the banking system is in doubt.

Since we abstract from runs and banks perfectly diversify idiosyncratic risk in our model, we view the assumptions on  $\Omega(\bar{b}_{t+1}^i, \bar{F}_{t+1})$  as convenient representation of the key collateral policy trade-off without greatly complicating the exposition: as we show below, lenient collateral policy increases both the aggregate default rate  $\bar{F}_{t+1}$  and aggregate collateral  $\bar{b}_{t+1}$ . The ambiguous impact on  $\Omega(\bar{b}_{t+1}^i, \bar{F}_{t+1})$  ensures an interior solution to the optimal collateral policy problem. Finally, making bank funding costs independent of fundamentals allows us to be consistent with the New Keynesian model, where the central bank effectively sets the nominal rate at which households save, i.e. the interest rate channel of monetary policy is operating without additional transmission channels.

**Bank Problem in Sub-Period 1.** We follow Cúrdia and Woodford (2011) and assume that bank maximize profits, defined as equity value net of liquidity management costs in (7), subject to the solvency condition (8). Taken the behaviour of other banks, firms and the Central Bank as given, the maximization problem of bank  $i$  reads

$$\max_{d_{t+1}^i, b_{c,t+1}^i, b_{g,t+1}^i} \Pi_t^i = d_{t+1}^i - q_{c,t+1} b_{c,t+1}^i - q_{g,t+1} b_{g,t+1}^i - \omega \cdot \Omega(\bar{b}_{t+1}^i, \bar{F}_{t+1}) \quad (7)$$

$$\text{s.t. } (1 + i_t^D) d_{t+1}^i = \mathbb{E}_t[\mathcal{R}_{c,t+1}] b_{c,t+1}^i + \mathbb{E}_t[\mathcal{R}_{g,t+1}] b_{g,t+1}^i. \quad (8)$$

The bond payoff  $\mathcal{R}_{\tau,t+1}$  depends on entrepreneur  $\tau$ 's bond issuance and capital choice via the default decision in period  $t + 1$ , which we describe below. Note that the bond payoff  $\mathcal{R}_{\tau,t}$  is not affected by the bond holding of an individual bank. Liquidity management costs drive a wedge into the bond price due to the willingness to pay for eligible bonds<sup>9</sup>

$$q_{\tau,t+1} = \frac{\mathbb{E}_t[\mathcal{R}_{\tau,t+1}]}{(1 + \phi_\tau \Omega_{b,t})(1 + i_t^D)}. \quad (9)$$

Holding eligible corporate bonds reduces the cost of settling liquidity deficits. Moreover, the collateral service premium is declining in the availability of collateral  $\bar{b}_{t+1}$ .

## 2.3 Firms and Entrepreneurs

**Final Good Producers.** There is a fixed mass of monopolistically competitive firms  $i \in [0, 1]$  that produce a differentiated good  $y_{i,t}$ . Each firm  $i$  produces its differentiated good using an

<sup>9</sup>Due to the symmetry of the bank problem and i.i.d. shocks, we can aggregate banks into a representative bank.

intermediate good,  $z$ , and labor,  $l$ . The production technology is given by

$$y_{i,t} = (1 - \mathcal{P}_t) A_t z_{i,t}^\theta l_{i,t}^{1-\theta}, \quad (10)$$

where  $A_t$  is an economy-wide TFP shock that evolves according to

$$\log(A_{t+1}) = (1 - \rho_A) \log(A_{ss}) + \rho_A \log(A_t) + \sigma_A \varepsilon_{t+1}^A, \quad \varepsilon_{t+1}^A \sim N(0, 1). \quad (11)$$

Final good production is negatively affected by pollution  $\mathcal{P}_t$  that is generated by the conventional entrepreneur. Final good firms sell their differentiated good with a markup over their marginal costs. However, the price of firm  $i$ ,  $P_{i,t}$ , can only be varied by paying a quadratic adjustment cost à la Rotemberg (1982) that is proportional to the nominal value of aggregate production,  $P_t y_t$ . Firm  $i$ 's marginal costs are denoted by  $\text{mc}_{i,t} \equiv \partial \mathcal{C}_t^W / \partial y_{i,t}$ , where

$$\mathcal{C}_t^W(y_{i,t}) = \min_{z_{i,t}, l_{i,t}} P_{z,t} z_{i,t} + W_t l_{i,t} \quad \text{s.t.} \quad y_{i,t} = (1 - \mathcal{P}_t) A_t z_{i,t}^\theta l_{i,t}^{1-\theta},$$

and  $P_{z,t}$  is the price of the wholesale good. From the minimization problem we obtain *real* marginal costs

$$\text{mc}_t = \frac{1}{(1 - \mathcal{P}_t) A_t} \left( \frac{p_{z,t}}{\theta} \right)^\theta \left( \frac{w_t}{1 - \theta} \right)^{1-\theta},$$

where  $p_{z,t} = P_{z,t}/P_t$  is the relative price of the wholesale good and  $w_t$  is the real wage. Hence, total nominal profits of firm  $i$  in period  $t$  are given by

$$\hat{\Pi}_{i,t} = (P_{i,t} - \text{mc}_t P_t) y_{i,t} - \frac{\psi}{2} \left( \frac{P_{i,t}}{P_{i,t-1}} - 1 \right)^2 P_t y_t,$$

where  $\psi$  measures the degree of nominal rigidity. Each wholesale good firm  $i$  maximizes the expected sum of discounted profits

$$\max_{P_{i,t+s}, y_{i,t+s}} \mathbb{E}_t \left[ \sum_{s=0}^{\infty} \beta^s \frac{c_{t+s}^{-\gamma} / P_{t+s}}{c_t^{-\gamma} / P_t} \hat{\Pi}_{i,t+s} \right],$$

subject to the demand schedule (1). Taking first-order conditions yields the New Keynesian Phillips Curve

$$\mathbb{E}_t \left[ \beta \left( \frac{c_{t+1}}{c_t} \right)^{-\gamma} \frac{y_{t+1}}{y_t} (\pi_{t+1} - 1) \pi_{t+1} \right] + \frac{\varepsilon}{\psi} (\text{mc}_t - \text{mc}^*) = (\pi_t - 1) \pi_t, \quad (12)$$

where  $mc^* \equiv \frac{\varepsilon-1}{\varepsilon}$  is the steady state real marginal cost.

**Wholesale Firm.** There is a competitive wholesale firm that bundles green and conventional intermediate goods into the homogeneous intermediate good used by final goods firms. Its technology is Cobb-Douglas

$$z_t = z_{g,t}^v z_{c,t}^{1-v}, \quad (13)$$

where  $v$  determines the relative share of the green intermediate sector versus the conventional one.<sup>10</sup> The prices of the intermediate good types  $\tau$  are denoted by  $P_{\tau,t}$ . Solving its profit maximization problem yields

$$v p_{z,t} z_t = p_{g,t} z_{g,t}, \quad (14)$$

$$(1-v) p_{z,t} z_t = p_{c,t} z_{c,t}, \quad (15)$$

where  $p_{\tau,t} \equiv \frac{P_{\tau,t}}{P_t}$  denotes the relative price of the respective intermediate good.

**Entrepreneurs: Technology.** Entrepreneurs produce the intermediate goods  $z_\tau$ ,  $\tau = \{g, c\}$ . Entrepreneurs are risk-neutral over (potentially negative) consumption and are relatively more impatient than the household so that they discount the future with a discount factor  $\tilde{\beta} < \beta$ . This assumptions ensures that entrepreneurs are borrowers in equilibrium. The production technology of the entrepreneur of type  $\tau$  is linear in capital and subject to an uninsurable idiosyncratic shock  $m_{\tau,t}$

$$z_{\tau,t} = m_{\tau,t} k_{\tau,t}. \quad (16)$$

Following Bernanke et al. (1999), the idiosyncratic shock is log-normally distributed with variance  $\varsigma_M$  and mean  $-\frac{\varsigma_M}{2}$  to ensure that  $\mathbb{E}[m] = 1$ . The log-normal distribution satisfies a monotone hazard rate property of the form  $\partial(h(m)m)/\partial m > 0$ , where  $h(m) = \frac{f(m)}{1-F(m)}$  denotes the hazard rate. Here,  $f(m)$  and  $F(m)$  denote the pdf and cdf, respectively. Capital  $k_{\tau,t}$  depreciates at rate  $\delta$ , which is common to both production technologies. Then, the law of motion for capital of entrepreneurs of type  $\tau$  is given by

$$k_{\tau,t+1} = i_{\tau,t} + (1-\delta)k_{\tau,t}, \quad (17)$$

<sup>10</sup>We assume that the pollution externality does not affect the wholesale firm, which does not internalize that its demand for conventional intermediate goods has adverse effects on aggregate final goods production. This eliminates the possibility of coordination among firms, which could arise if final goods producers directly used intermediate goods as an input.

where  $i_{\tau,t}$  denotes entrepreneurial investment.

**Entrepreneurs: Financial Side.** Entrepreneurs either finance their activities by issuing equity, modelled as negative consumption, or by issuing bonds. Following Gomes et al. (2016), these are nominal discount bonds with stochastic maturity, promising to pay one unit of the numeraire in  $t + 1$  with probability  $s$  in case of repayment.<sup>11</sup> With probability  $1 - s$  the bond does not mature and is rolled over at next period's market price  $q_{\tau,t+1}$ . In case of default, banks holding distressed bonds effectively replace the entrepreneur as shareholder: they seize the output *only in the default period*, restructure the firm, and resume to being creditors after the entrepreneur's debt has been restructured. Importantly, bonds that do not mature are assumed to be unaffected by the restructuring process, i.e. they are simply rolled over. While in practice, restructuring takes several periods, we follow Gomes et al. (2016) and take a shortcut by assuming that capital owners are able to renegotiate the financial structure without delay in the default period. This shortcut facilitates aggregation into a representative entrepreneur. The maximization problem (in real terms) of a type  $\tau$  entrepreneur is given by

$$\begin{aligned} V^E(b_{\tau,t}, k_{\tau,t}) &= \max_{b_{\tau,t+1}, k_{\tau,t+1}} \tilde{c}_{\tau,t} + \tilde{\beta} \mathbb{E}_t [V^E(b_{\tau,t+1}, k_{\tau,t+1})] \quad \text{s.t.} \\ \tilde{c}_{\tau,t} &= (1 - G(\bar{m}_{\tau,t})) p_{\tau,t} (1 - \chi_{\tau}) k_{\tau,t} - i_{\tau,t} - (1 - F(\bar{m}_{\tau,t})) s b_{\tau,t} + q(\bar{m}_{\tau,t+1}) (b_{\tau,t+1} - (1 - s) b_{\tau,t}) , \\ \bar{m}_{\tau,t} &\equiv \frac{s b_{\tau,t}}{\pi_t p_{\tau,t} (1 - \chi_{\tau}) k_{\tau,t}} , \end{aligned}$$

where the default productivity threshold is given by  $\bar{m}_{\tau,t}$ . This threshold is implicitly defined through the productivity level at which the entrepreneur is indifferent between defaulting and loosing revenues  $m_{\tau,t} p_{\tau,t} k_{\tau,t}$ , or repaying nominal debt obligations  $s b_{\tau,t}$ . The term  $G(\bar{m}_{\tau,t}) \equiv \int_0^{\bar{m}_{\tau,t}} m dF(m)$  is the average productivity of defaulting entrepreneurs and  $F(\bar{m}_{\tau,t}) \equiv \int_0^{\bar{m}_{\tau,t}} dF(m)$  is the default probability. In case of default, the bank pays restructuring costs  $\varphi$  and is entitled to the entire production output, valued at price  $p_{\tau,t+1}$ , while the nominal payoff in case of repayment is  $b_{\tau,t+1} P_{t+1}$ .<sup>12</sup> In summary, the *real per-unit* bond payoff is

$$\mathcal{R}_{\tau,t} = s \left( G(\bar{m}_{\tau,t}) \frac{\pi_t p_{\tau,t} (1 - \chi_{\tau}) k_{\tau,t}}{s b_{\tau,t}} + 1 - F(\bar{m}_{\tau,t}) \right) - F(\bar{m}_{\tau,t}) \varphi + (1 - s) q_{\tau,t} . \quad (18)$$

The first term reflects the payoff from maturing bonds: the first part represents production revenues banks seize in default while the second part represents repayment of the principal. The term  $F(\bar{m}_{\tau,t}) \varphi$  reflects default costs incurred by banks. The share of bonds that are rolled over

<sup>11</sup> Making bonds long-term enables us to generate realistic leverage ratios in the calibration, but is not required for the transmission of collateral policy.

<sup>12</sup> Attributing restructuring costs to entrepreneurs yields similar mechanics, but is notationally more intensive.



is valued at the bond market price  $q_{\tau,t}$ . The parameter  $\chi_\tau$  is a time-invariant tax on production of entrepreneur  $\tau$ . When it is negative, it can be interpreted as a subsidy and will be set to zero in the baseline calibration.<sup>13</sup>

**Entrepreneurs: Bond Issuance and Investment.** As in Gomes et al. (2016), the bond price depends only the default threshold  $\bar{m}_{\tau,t}$ . Plugging in real investment (17) and banks' bond pricing condition (9) into the Bellman equation, the first-order conditions for bond issuance and capital holdings read

$$q'(\bar{m}_{\tau,t+1}) \frac{\bar{m}_{\tau,t+1}}{b_{\tau,t+1}} \left( b_{\tau,t+1} - (1-s) \frac{b_{\tau,t}}{\pi_t} \right) + q(\bar{m}_{\tau,t+1}) = \tilde{\beta} \mathbb{E}_t \left[ \frac{s(1-F(\bar{m}_{\tau,t+1})) + (1-s)q_{\tau,t+1}}{\pi_{t+1}} \right] \quad (19)$$

and

$$1 = -q'(\bar{m}_{\tau,t+1}) \frac{\bar{m}_{\tau,t+1}}{k_{\tau,t+1}} \left( b_{\tau,t+1} - (1-s) \frac{b_{\tau,t}}{\pi_t} \right) + \tilde{\beta}(1-\delta) + \tilde{\beta}(1-\chi_\tau) \mathbb{E}_t[p_{\tau,t+1}] (1-G(\bar{m}_{\tau,t+1})) . \quad (20)$$

The analytical steps are relegated to appendix A.2. Equation (19) is a standard optimality condition equating the marginal benefit of issuing more bonds (LHS) with the marginal costs (RHS). Each additional unit of bonds increases funds available in period  $t$  by  $q(\bar{m}_{\tau,t+1})$  units. At the same time, the bond price schedule is a decreasing function of the default threshold, which we also refer to as the *risk choice*. Since we characterize bond prices by the risk choice  $\bar{m}_{\tau,t+1}$ , the term  $\frac{\bar{m}_{\tau,t+1}}{b_{\tau,t+1}}$  captures the increase of default risk arising from the issuance of an additional unit of bonds. This dilutes the value of existing bond investment  $b_{\tau,t+1} - (1-s) \frac{b_{\tau,t}}{\pi_t}$ . Due to the concave shape of the debt issuance Laffer curve, the amount of funds available increases in leverage at a diminishing rate up to a certain point. After this point, the dilution effect dominates, and available funds decrease in leverage. Choosing leverage beyond this point is not optimal.

The period- $t$  leverage choice has also implications for entrepreneur consumption in  $t+1$ . Each unit of bonds involves repayment of  $s$ , conditional on not defaulting. At the same time, leverage increases the break-even productivity level  $\bar{m}_{\tau,t+1}$  in  $t+1$ , which makes default more likely and, thereby, decreases expected repayment  $1-F(\bar{m}_{\tau,t+1})$ . In addition, bond issuance also increases the rollover burden in  $t+1$ . Since bonds are nominal, both effects decline if expected inflation is high, such that the leverage choice positively responds to expected inflation.

<sup>13</sup>It is not relevant in our setup, whether the entrepreneurs or wholesale firms pay the tax. Attributing it to the entrepreneurs however gives the cleanest comparison to collateral policy, which both operate through the entrepreneurial investment decision in our model.

The optimality condition for capital (20) is a simple trade-off between the cost of capital (LHS) and the increase in consumption at  $t$  and  $t + 1$  (RHS). The latter consists of the capital value after depreciation, the marginal value of production net of taxes, and the increase of the bond price stemming from a decrease of the default probability. Increases in the bond price affect consumption in period  $t$ , while capital and production value are discounted with the factor  $\tilde{\beta}$ .

## 2.4 Public Policy and Resource Constraint

The Central Bank specifies the collateral framework  $(\phi_c, \phi_g)$  and the sets policy rate  $i_t^D$  according to a Taylor rule

$$i_t^D = i^D \pi_t^{\phi_\pi} . \quad (21)$$

The fiscal authority runs a balanced budget

$$\chi_c p_{c,t} z_{c,t} = \chi_g p_{g,t} z_{g,t} . \quad (22)$$

The subsidy on green output is completely financed by a tax on conventional goods and there are no further fiscal instrument needed to balance the government budget. Since there are also no central bank profits in this model, this ensures a fair comparison between collateral frameworks and fiscal instruments. The resource constraint closes the model

$$y_t = c_t + \sum_{\tau} (c_{\tau,t} + i_{\tau,t}) + \Omega(\bar{b}_{t+1}) + \frac{\psi}{2} (\pi_t - 1)^2 y_t + \sum_{\tau} \phi F(\bar{m}_{\tau,t}) \frac{b_{\tau,t}}{\pi_t} . \quad (23)$$

## 2.5 Policy Transmission in a Simplified Setting

While in the full model, the optimal choice of nominal long-term bonds is affected by the maturity structure and inflation, the transmission of Central Bank collateral policy can be illustrated in a simplified setting. We consider a special case with  $s = \pi = \delta = 1$ , i.e. in a real model with one-period bonds and full capital depreciation. To focus on entrepreneur's financial frictions, we normalize the intermediate goods prices to one, abstract from labor in the production function, and shut off aggregate risk. We begin by characterizing the impact of preferential treatment and taxation on entrepreneurs, who make the investment decision in our model.

**Entrepreneurs.** The entrepreneur budget constraint is given by

$$\tilde{c}_{\tau,t} + k_{\tau,t+1} = q(\bar{m}_{\tau,t+1}) b_{\tau,t+1} + (1 - G(\bar{m}_{\tau,t})) k_{\tau,t} - (1 - F(\bar{m}_{\tau,t})) b_{\tau,t} .$$

and the default threshold simplifies to  $\bar{m}_{\tau,t+1} = \frac{b_{\tau,t+1}}{(1-\chi_\tau)\mathbb{E}_t[p_{\tau,t+1}]k_{\tau,t+1}}$ . The first-order conditions for bonds and capital are given by

$$q'(\bar{m}_{\tau,t+1})\bar{m}_{\tau,t+1} + q(\bar{m}_{\tau,t+1}) = \tilde{\beta}(1 - F(\bar{m}_{\tau,t+1})), \quad (24)$$

$$1 + q'(\bar{m}_{\tau,t+1})\frac{\bar{m}_{\tau,t+1}}{k_{\tau,t+1}}b_{\tau,t+1} = \tilde{\beta}(1 - \chi_\tau)\mathbb{E}_t[p_{\tau,t+1}](1 - G(\bar{m}_{\tau,t+1})) \quad (25)$$

In the simplified setting, the leverage choice equates additional consumption in the current period with the expected repayment in the next period, discounted with  $\tilde{\beta}$ . The capital choice equates the capital price (normalized to one) and the bond price appreciation due to a higher default threshold with the expected (after-tax) payoff from the investment.

Without aggregate risk, the deposit rate equals the inverse household discount factor  $i_t^D = 1/\beta - 1$  such that the bond price is  $q(\bar{m}_{\tau,t+1}) = \beta \frac{1 - F(\bar{m}_{\tau,t+1}) - \phi F(\bar{m}_{\tau,t+1})}{1 + \phi_\tau \Omega_{b,t}}$ . Plugging this into the first-order condition for bonds, (24) can be written as

$$\left( \frac{\beta}{1 + \phi_\tau \Omega_{b,t}} - \tilde{\beta} \right) (1 - F(\bar{m}_{\tau,t+1})) = \beta \phi \frac{F'(\bar{m}_{\tau,t+1})\bar{m}_{\tau,t+1} + F(\bar{m}_{\tau,t+1})}{1 + \phi_\tau \Omega_{b,t}}.$$

Dividing by  $1 - F(\bar{m}_{\tau,t+1})$  this can be expressed in terms of the hazard rate  $h(\bar{m}_{\tau,t+1})$

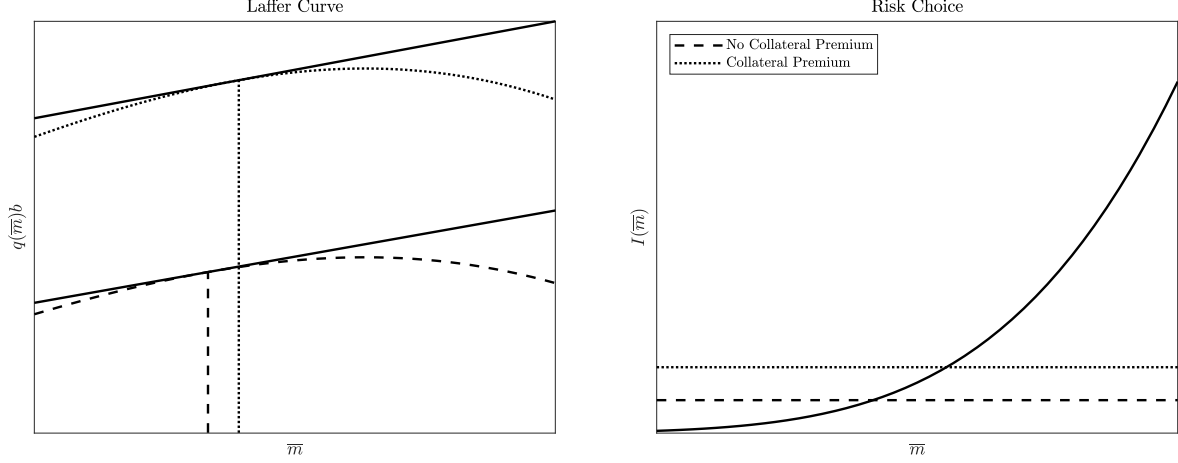
$$\frac{\beta - (1 + \phi_\tau \Omega_{b,t})\tilde{\beta}}{\beta} = I(\bar{m}_{\tau,t+1})\phi \quad \text{with} \quad I(\bar{m}_{\tau,t+1}) \equiv \frac{F(\bar{m}_{\tau,t+1})}{1 - F(\bar{m}_{\tau,t+1})} + h(\bar{m}_{\tau,t+1})\bar{m}_{\tau,t+1}. \quad (26)$$

In the absence of collateral premia, i.e. in the case of  $\Omega_{b,t} = 0$ , entrepreneurs' risk choice (the default threshold  $\bar{m}_{\tau,t+1}$ ) is determined by equating relative impatience  $\frac{\beta - \tilde{\beta}}{\beta}$  and marginal default costs  $\phi I(\bar{m}_{\tau,t+1})$ . Collateral premia drive a wedge into this trade-off: whenever  $\phi_\tau > 0$ , the left-hand side of (26) increases, since  $\Omega_{b,t} < 0$ . Due to the monotonicity assumption of the hazard rate  $h(\bar{m}_{\tau,t+1})$  and the monotonicity property of the default/repayment odds ratio, on the right-hand side,  $I(\bar{m}_{\tau,t+1})$  increases in  $\bar{m}_{\tau,t+1}$ . Thus, the optimal leverage choice  $\bar{m}_{\tau,t+1}$  is increasing in the collateral premium  $\phi_\tau \Omega_{b,t}$ , as in Kaldorf and Wicknig (2021).

In the left panel of Figure 3, we show how collateral premia induce an outward shift of debt Laffer curves. These curve represent the amount of resources entrepreneurs can raise by issuing a specific amount of bonds and are directly affected by collateral policy via the bond pricing equation of banks. In this figure, the indifference curves are shown as solid lines and the optimal bond issuance is pinned down by the value of  $\bar{m}$ , where debt Laffer curve and entrepreneur indifference curves are tangential. Since collateral premia affect bond prices in a proportional way, they shift the tangential point to the right, i.e. they induce risk-taking. Equivalently, the right panel of Figure 3 graphically illustrates (26). The solid line indicates the risk-taking

function  $I(\bar{m}_{\tau,t+1})$  for the log-normal distribution on the RHS of (26). The horizontal lines represent the LHS of (26), where the dotted line obtains from plugging in  $\Omega_{b,t} = 0$  (no collateral premia) and the dashed line from plugging in a positive collateral premium.

Figure 3: Entrepreneur Choice with and without Collateral Premia



Since in our model, higher leverage  $\bar{m}_{\tau,t+1}$  is associated with higher default rates by construction, an increase in collateral policy parameters will induce an increase in default risk. While borrowing and investment are determined jointly in equilibrium, this argument demonstrates that - irrespective of the parametrization - the change in investment is bounded from above by the change in bonds outstanding. Moreover, funds raised but not invested are paid out as dividends, as documented empirically by Todorov (2020). In contrast, the tax (or subsidy) on intermediate goods does not affect the risk choice (26).

**Equilibrium Capital Shares.** How do these instruments affect the equilibrium share of capital invested in the green and conventional technologies? When abstracting from labor, the production technologies of wholesale and final goods producers can be consolidated into a production function which exhibits decreasing returns to scale due to the pollution externality

$$z_t = \exp\{-\gamma_P k_{c,t}\} k_{c,t}^{1-\nu} k_{g,t}^{\nu}. \quad (27)$$

Using the consolidated production function together with the demand for both intermediate goods (14) and (15), the government budget constraint (22) can be rearranged for the budget clearing subsidy on green intermediate goods, given a tax rate  $\chi_c$ :

$$\chi_g = -\frac{1-\nu}{\nu} \chi_c. \quad (28)$$

Combining the investment decision (25) for both entrepreneur types with the intermediate good demand (14), (15), and the production technology (27) we can relate market clearing investment  $k_{\tau,t}$  to the risk-choice  $\bar{m}_{\tau,t+1}$ :

$$\begin{aligned} 1 &= \left( -q'_{c,t} \bar{m}_{c,t+1}^2 + \tilde{\beta}(1 - G(\bar{m}_{c,t+1})) \right) (1 - v)(1 - \chi_c) \exp\{-\gamma_P k_{c,t+1}\} k_{g,t+1}^v k_{c,t+1}^{-v}, \\ 1 &= \left( -q'_{g,t} \bar{m}_{g,t+1}^2 + \tilde{\beta}(1 - G(\bar{m}_{g,t+1})) \right) v \left( 1 + \frac{1-v}{v} \chi_c \right) \exp\{-\gamma_P k_{c,t+1}\} k_{g,t+1}^{v-1} k_{c,t+1}^{1-v}. \end{aligned}$$

These conditions can be combined into the equilibrium ratio of green and conventional capital.

$$\frac{k_{g,t}}{k_{c,t}} = \frac{\left( v + (1-v)\chi_c \right)}{(1-v)(1-\chi_c)} \cdot \frac{-q'_{g,t} \bar{m}_{g,t+1}^2 + \tilde{\beta}(1 - G(\bar{m}_{g,t+1}))}{-q'_{c,t} \bar{m}_{c,t+1}^2 + \tilde{\beta}(1 - G(\bar{m}_{c,t+1}))} \quad (29)$$

The ratio depends on the tax on intermediate goods and the risk-taking decision of entrepreneurs. Absent fiscal policy and preferential treatment, (29) simplifies to  $\frac{v}{1-v}$ , i.e. the green capital share is pinned down by its Cobb-Douglas parameter in the production technology.<sup>14</sup> Equation (29) reveals that fiscal policy can *directly* affect the capital ratio by levying a positive tax on intermediate goods. Setting  $\chi_c > 0$  in the first term of (29) increases the green capital ratio above  $\frac{v}{1-v}$  while leaving the financial frictions of entrepreneurs unchanged. However, changing  $k_{c,t}$  and  $k_{g,t}$  while keeping  $\bar{m}_{c,t}$  and  $\bar{m}_{g,t}$  constant naturally implies changes to  $b_{c,t}$  and  $b_{g,t}$ , i.e. there are second round effects on the financial stability trade-off determining collateral policy. In contrast, the Central Bank can *indirectly* affect the capital allocation by affecting the risk-choice of entrepreneurs through preferential treatment. Specifically, the numerator and denominator of the second term in (29) can be expressed as

$$\begin{aligned} & -q'_{\tau,t} \bar{m}_{\tau,t+1}^2 + \tilde{\beta}(1 - G(\bar{m}_{\tau,t+1})) \\ &= \tilde{\beta} + \frac{\beta}{1 + \phi_{\tau} \Omega_B} \phi F'(\bar{m}_{\tau,t+1}) \bar{m}_{\tau,t+1}^2 + \left( \frac{\beta}{1 + \phi_{\tau} \Omega_B} - \tilde{\beta} \right) G(\bar{m}_{\tau,t+1}). \end{aligned}$$

This term increases in  $\bar{m}_{\tau,t+1}$ , since  $F''(\bar{m}_{\tau,t+1}) > 0$  on the relevant part of the debt Laffer curve. As shown above, preferential treatment induces an increase of  $\bar{m}_{g,t+1}$ , while at the same time  $\bar{m}_{c,t+1}$  decreases. This translates into an increase in the green capital ratio. The very nature of this intervention introduces adverse side effects on risk-taking and ultimately dampens the transmission of preferential treatment to capital shares.

<sup>14</sup>Solving the planner problem in an economy without the financial friction yields a (time-invariant) green capital ratio of  $\frac{k_g}{k_c} = \frac{v}{1-v-\gamma_P k_c}$ . This ratio exceeds the competitive equilibrium ratio of  $\frac{v}{1-v}$  whenever  $\gamma_P > 0$ . Furthermore, in this simple economy, this ratio pins down a tax rate  $\chi_c$  implementing the planner solution. Whenever the economy is subject to financial frictions, the implementation of environmental policy naturally interferes with financial stability. We shed light on these interactions in our quantitative analysis.

### 3 Calibration

In this section, we provide a calibration of the model to European data. Each period corresponds to one quarter. All parameters regarding nominal rigidities, household preferences, and investment dynamics are set to standard values used in the literature. We assume log-utility over consumption, fix the inverse of Frisch elasticity at 1, and set the household discount factor  $\beta$  to 0.99. We set the Cobb-Douglas coefficient,  $\theta$ , to  $1/3$  to get a labor share of  $2/3$ , and we set the weight  $\omega_L$  in the household utility function to be consistent with a steady state labor supply of  $1/3$ . We choose a standard parameter on inflation stabilization in the monetary policy rule  $\phi_\pi = 1.5$ . The TFP shock parameters are conventional values in the New Keynesian literature.

Parameters regarding pollution and the green technology share are important drivers of environmental DSGE models. To ensure that our results are not solely driven by parameter choices, we provide robustness checks for environmental parameters in appendix B. For the relative share of the green sector, we use the most recent data on the share of renewable energies in the Euro Area. Although this is only a subset of intermediate goods, it has the advantage that, since renewable energy is a prominent feature of the public discussion, the data quality is excellent. From this data-set we find that the relative share of the green sector is 20%, which directly informs the Cobb-Douglas parameter of the wholesale goods producers  $v$ .<sup>15</sup>

In spirit of Heutel (2012) and Golosov et al. (2014), we assume that damage of pollution can be expressed as

$$\mathcal{P}_t = 1 - \exp\{-\gamma_P z_{c,t}\}, \quad (30)$$

which, through final good production (10), generates a percentage loss in the production of the final good producer. The function captures the mapping from pollution to real economic damage and the parameter  $\gamma_P$  governs the pass-through from pollution to production losses. We inform the parameter  $\gamma_P$ , governing the externality of conventional production, using estimates of direct costs from pollution and indirect costs from adverse environmental conditions. From the model, we can directly relate this quantity  $1 - \exp\{-\gamma_P z_c\}$  to observable (long-run) quantities  $1 - y/z^\theta l^{1-\theta}$ . We use the estimate of Muller (2020), who quantifies Damage/GDP at 10% in 2016 for the US. The value of 0.1 has also been reported in the fourth National Climate Assessment in the US (Reidmiller et al., 2018).<sup>16</sup> Since economic activity in this dimension can be assumed to be similar in the US and the Euro area, we adopt the same value.<sup>17</sup> Rearranging

<sup>15</sup>Renewable energy statistics for the EU are accessible [here](#). See also the guide by the Statistical Office of the European Union, 2020. Using a higher value of  $v = 0.4$  in appendix B does not change the results of our policy experiments.

<sup>16</sup>See also “U.S. Climate Report Warns of Damaged Environment and Shrinking Economy,” New York Times, November 23, 2018.

<sup>17</sup>In appendix B, we provide robustness checks for a lower value of  $\gamma_P$ , which implies a steady state pollution/GDP

yields the steady relationship

$$\gamma_P = -\frac{\log(y/(z^\theta l^{1-\theta}))}{z_c}. \quad (31)$$

The next group of parameters is associated with financial frictions on the entrepreneur side. Average maturity of corporate bonds corresponds to the mean time to maturity in the *Markit iBoxx* corporate bond index between 2010 and 2019, which is five years, i.e.  $s = 0.05$ . Following Gomes et al. (2016), the resource losses of default  $\phi$  are set such that they are consistent with a recovery rate of 30%, defined as realized payoff in default over the promised payoff. For the remaining parameters, we match targets concerning corporate debt and default dynamics. The liquidity deficit  $\omega$  is set to be consistent with the ratio of interbank market turnover to GDP, as reported in the European Money Market Study 2018. The entrepreneur discount factor  $\tilde{\beta}$  and idiosyncratic productivity variance  $\sigma_M$  are set to match time-series means of spreads and leverage. The model-implied bond spread is defined as

$$x_{\tau,t} \equiv (1 + s/q_{\tau,t} - s)^4 - (1 + i_t^D)^4. \quad (32)$$

For the data moment, we use the *IHS Markit* data from 2010 until 2019 and compute the median bond spread over the entire corporate bond market, i.e. the Investment Grade and High Yield segments, which yields a value of around 100bp. Liquidity management costs are specified as

$$\Omega(\bar{b}_t^i, \bar{F}_t) = \omega \cdot \max \left\{ \eta_0 \bar{F}_t^2 - \frac{l_0}{2} \left( \frac{\bar{b}_t^i}{\omega} \right)^{0.5}, 0 \right\}. \quad (33)$$

The parameter  $\eta_0$  determines the impact of corporate default risk, while  $l_0$  is the slope of the cost reduction per unit of collateral. Plugging in  $\bar{b}_{t+1}^i = 0$  can be interpreted as the cost level of an entirely un-collateralized banking system. We ensure in the calibration that this term is always positive. The marginal cost reduction is obtained from differentiating (33) with respect to total available collateral

$$\Omega_{b,t} = -l_0 (\bar{b}_{t+1})^{0.5} (\omega)^{0.5}. \quad (34)$$

The parameter  $\eta_0$  is not identified in our model, since it does not affect the competitive equilibrium: specifically, it has no impact on bond prices. Instead, it gives us an additional degree of freedom regarding the collateral framework, since we set it ex-post and such that  $\phi_{sym} = 0.23$ , which is the value generating the amount of eligible bonds observed in the data, is optimal according to an utilitarian welfare criterion. In the baseline calibration, we impose symmetric

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ratios of 5%, corresponding to the moment used in Carattini et al. (2021).

collateral treatment  $\phi_{sym} \equiv \phi_c = \phi_g$ . The amount of eligible corporate bonds is taken from the ECB [website](#). Put differently, we assume that the current ECB collateral policy is optimal under the restriction of no preferential treatment and parametrize our liquidity management cost function accordingly.

Table 1: Baseline Calibration

Parameter	Value	Source/Target
<i>Households</i>		
CRRA-coefficient $\gamma_C$	1	log-utility
Household discount factor $\beta$	0.99	Annual riskless rate 4%
Labor disutility convexity $\gamma_L$	1	Frisch elasticity = 1
Labor disutility weight $\omega_L$	6.68	Labor supply = 1/3
<i>Firms</i>		
Final goods elasticity $\varepsilon$	6	Markup = 20%
Rotemberg parameter $\psi$	57.8	Consistent with Calvo parameter of 0.75
Cobb-Douglas coefficient $\theta$	1/3	Labor share = 2/3
Green goods share $\nu$	0.20	Renewable Energy Share in Europe 2018
Externality Parameter $\gamma_P$	1.5e-2	Pollution damage/GDP = 0.1
<i>Banks</i>		
Bond maturity parameter $s$	0.05	<i>IHS Markit</i>
Restructuring cost $\varphi$	0.5	Recovery rate = 30%
Liquidity deficit $\omega$	2.25	Interbank Turnover/GDP = 3
Liquidity management parameter $\eta_0$	74.5	Ex-post optimality of $\phi_{sym} = 0.23$
Liquidity management parameter $l_0$	0.004	Collateral service premium = -7bp
<i>Entrepreneurs</i>		
Depreciation rate $\delta$	0.067/4	Capital/GDP = 2.1
Entrepreneurs' discount factor $\tilde{\beta}$	0.9845	Debt/GDP = 0.8
Stdev of idiosyncratic risk $\zeta_M$	0.19	Bond spread = 100bp
<i>Central Bank</i>		
Monetary policy rule $\phi_\pi$	1.5	Standard
Collateral parameter $\phi_{sym}$	0.23	Collateral/GDP = 0.15
<i>Shocks</i>		
Persistence TFP shock $\rho_A$	0.95	Standard
Variance TFP shock $\sigma_A$	0.005	Standard

The slope of the liquidity management cost function is calibrated to  $l_0 = 0.004$ , matching the



collateral service premium in the data. We target the point estimate of -7bp from Pelizzon et al. (2020) and Mésonnier et al. (2020).<sup>18</sup> The model implied collateral service premium is given by the yield differential of the traded bond and a synthetic bond that is not eligible in period  $t$ , corresponding to the identification strategy of Pelizzon et al. (2020). Formally, we have

$$x_{\tau,t} \equiv (1 + s/q_{\tau,t} - s)^4 - (1 + s/(q_{\tau,t}(1 + \phi_{\tau}\Omega_{b,t})) - s)^4. \quad (35)$$

Finally, we define the *greenium* as the spread of conventional over green bonds with corresponding maturity

$$\hat{x}_t = x_{g,t} - x_{c,t}. \quad (36)$$

Our baseline calibration is summarized in Table 1.

## 4 Policy Analysis

In this section, we conduct several policy experiments regarding the collateral framework. First, we illustrate the basic collateral policy trade-off under symmetric treatment, before turning to preferential treatment. Finally, we consider the case of environmental policy implemented by the fiscal authority.

### 4.1 Collateral Policy with Symmetric Treatment

We start the analysis with an illustration of collateral policy under symmetric collateral treatment of green and conventional bonds. Taxes and subsidies are set to zero. The discussion is centered around the utilitarian welfare criterion based on household's unconditional expected utility (2). Following Schmitt-Grohé and Uribe (2007), we evaluate unconditional welfare by approximating it, together with the policy functions, up to second order.<sup>19</sup> We then compute welfare gains of adopting an alternative policy with respect to the baseline policy in terms of consumption equivalent (CE), defined as the additional fraction of consumption that the household living in the baseline economy would need to receive each period to be as better off as the household living in the alternative economy. Given the log-utility assumption on consumption,

<sup>18</sup>Using the ECB list of collateral eligible for main refinancing operations, Pelizzon et al. (2020) identify a collateral premium of -7bp. Mésonnier et al. (2020) also identify an eligibility premium of -7b using a surprise relaxation of eligibility criteria prior to the ECB's additional credit claims program.

<sup>19</sup>We also look at welfare gains conditionally on being at the baseline steady state and thus explicitly considering the transition period to the new steady state. Results are virtually unchanged.

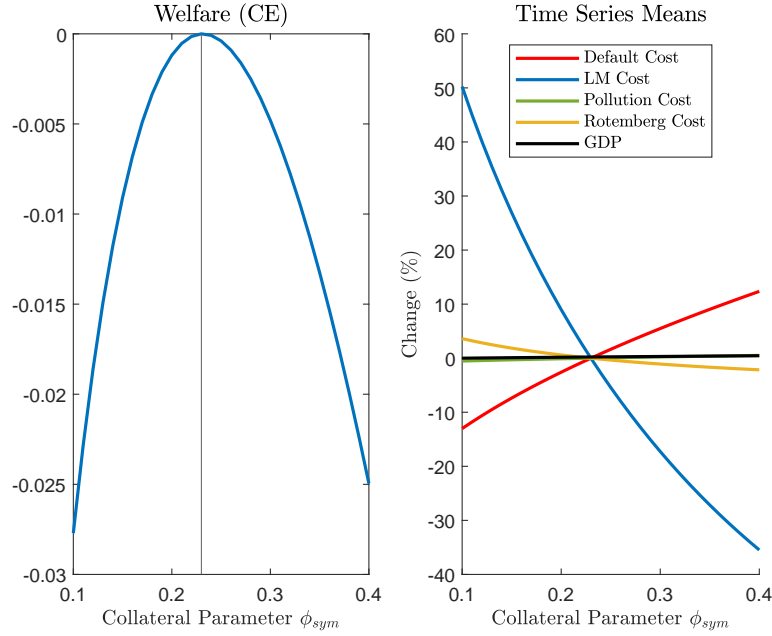
the consumption equivalent welfare gain has the following expression:

$$c^{CE.policy} \equiv 100 \left( \exp\{(1 - \beta)(V^{policy} - V^{base})\} - 1 \right), \quad (37)$$

where  $V^{base}$  and  $V^{policy}$  are obtained from evaluating (2) under the baseline and alternative policies, respectively. The CE is defined as the fraction of the baseline consumption path that the household would need to receive to be indifferent between baseline and alternative policy.

As outlined in our calibration, the parameter  $\eta_0$  is chosen such that welfare reaches its peak at  $\phi_{sym} = 0.23$ , which is consistent with the empirically observed level of collateral supply. In the left panel of Figure 4, we plot welfare gains in terms of consumption equivalents. A negative value therefore represents a welfare loss.

Figure 4: Welfare Under Symmetric Collateral Policy



Notes: Welfare (left panel) is defined as recursive household utility and calculated for varying symmetric collateral policy  $\phi_{sym}$ . The right panel plots welfare relevant cost terms. All values relative to the baseline calibration.

The right hand panel of Figure 4 provides a decomposition into model-implied means of all welfare relevant costs terms: liquidity management, default, pollution, and Rotemberg cost. These terms affect the amount of available resources for private consumption via (23). While the pollution externality does not show up directly in the resource constraint, it affects production on the left-hand side through its impact on total factor productivity. There is only a small reaction of Rotemberg costs in absolute and relative terms (see Table 2), which implies that collateral policy is entirely shaped by the financial stability trade-off: a higher collateral parameter increases availability of collateral, such that liquidity management costs decrease,

ceteris paribus. This effect declines with  $\phi_{sym}$  due to the convexity of the liquidity management cost in aggregate collateral. On the other hand, there is an increase in average default costs associated with higher risk-taking by entrepreneurs that take advantage of cheaper financing conditions. Optimal collateral policy balances these two effects. Pollution slightly increases in  $\phi_{sym}$ , since collateral premia increase investment which has an expansionary effect.

## 4.2 Collateral Policy with Preferential Treatment

The analysis proceeds in two steps. First, we optimize welfare over the green collateral parameter  $\phi_g$ , fixing  $\phi_c$ , and will refer to this policy as *simple preferential treatment*. In the second experiment, we remove the constraint on  $\phi_c$  and compute the welfare maximum over the entire Central Bank policy space  $(\phi_c, \phi_g)$ . We will refer to this as the *optimal collateral policy*. Time series means of these policies are shown in the second and third column of Table 2.

Table 2: Time Series Means for Different Policies

Moment	Baseline	Simple Pref	Optimal Coll	Simple Tax	Glob Optimum
Tax Parameter $\chi_c$	0	0	0	0.07	0.07
Coll. Parameter $\phi_g$	0.23	0.54	0.56	0.23	0.25
Coll. Parameter $\phi_c$	0.23	0.23	0.14	0.23	0.25
Welfare Change (CE)	0%	0.014%	0.021%	0.3497%	0.35%
Conv. Bonds	1.909	1.905	1.889	1.781	1.783
Green Bonds	0.477	0.490	0.493	0.613	0.613
Conv. Leverage	39.2%	39.1%	38.9%	39.2%	39.2%
Green Leverage	39.2%	39.7%	39.8%	39.2%	39.2%
Conv. Bond Spread	100bp	105bp	116bp	100bp	99bp
Green Bond Spread	100bp	57bp	43bp	100bp	99bp
Conv. Coll. Premium	-7bp	-6bp	-5bp	-7bp	-8bp
Green Coll. Premium	-7bp	-15bp	-18bp	-7bp	-8bp
GDP	0.7462	0.7470	0.7463	0.7449	0.7451
Rotemberg Cost	5.7e-05	5.7e-05	5.7e-05	5.9e-05	5.8e-05
Default Cost	0.0101	0.0106	0.0101	0.0101	0.0103
Liquidity Management Cost	0.0020	0.0017	0.0021	0.0020	0.0019
Pollution Cost	0.0750	0.0750	0.0747	0.0702	0.0702
Green Bond Share	20.00%	20.45%	20.69%	25.60%	25.60%
Green Capital Share	20.00%	20.21%	20.32%	25.60%	25.60%

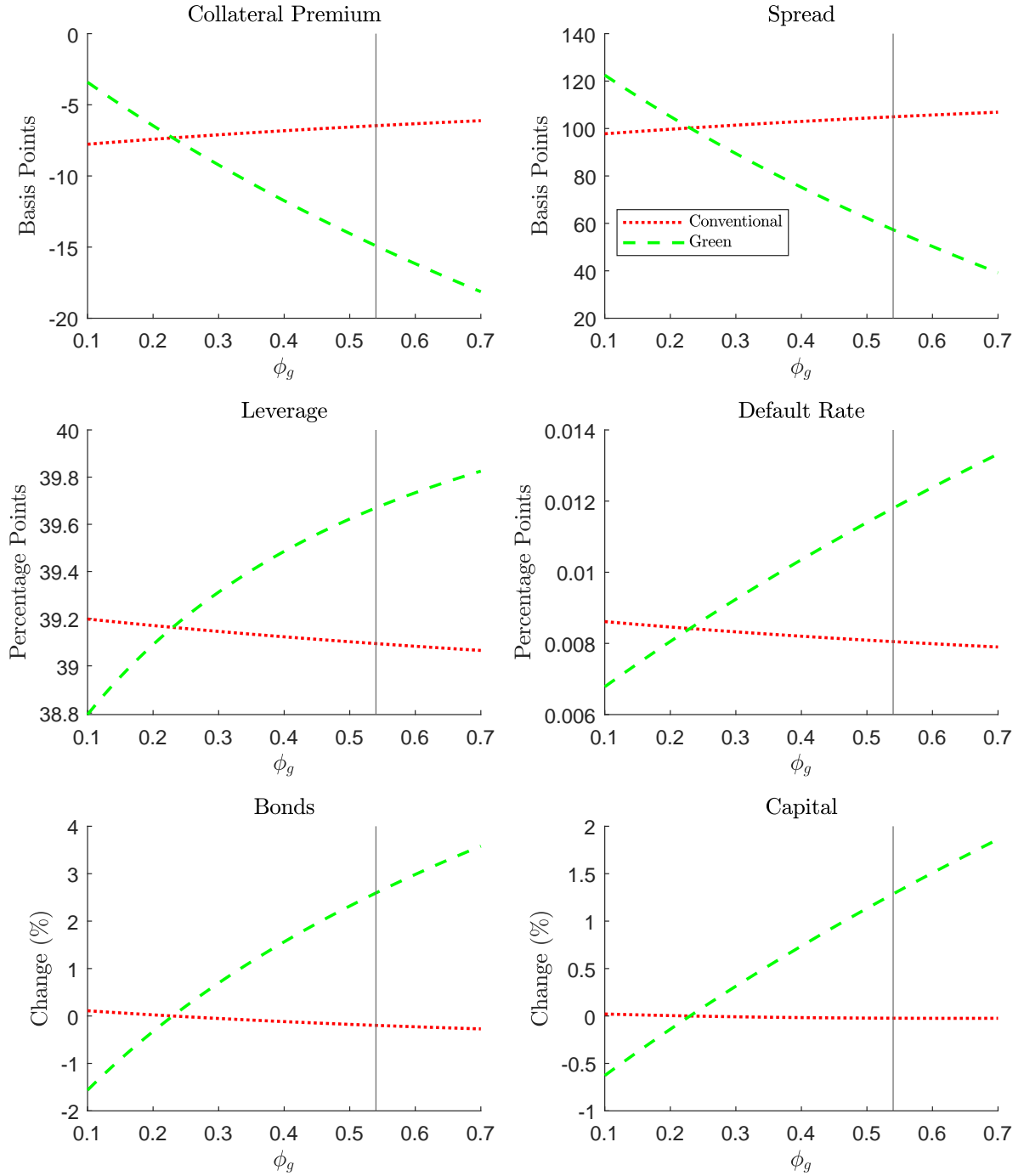
**Simple Preferential Treatment.** Consider first the case of simple preferential treatment (second column). A comparison to the baseline case (first column) reveals that Central Bank policy is not neutral in the long-run. The substantially higher collateral premium of green bonds translates into a greenium of 48bp, which is close to the yield reaction of Chinese green bonds (46bp), following the introduction of preferential treatment by the PBoC in 2018 (see Macaire and Naef, 2021).

As a result, green firms increase bond issuance and investment, where bond issuance (0.45 percentage points) is much more responsive than investment (0.21 percentage points). Less than 50% of the initial effect on the corporate bond market does not carry over to the investment decision, due to the financial friction on entrepreneurs. The converse holds for conventional entrepreneurs, who reduce their capital holdings in equilibrium, which in turn reduces the pollution externality. However, the expansion of green leverage exceeds the contraction of conventional leverage, which has adverse effects by raising default cost. At the same time, liquidity management costs decline due to the increased aggregate collateral. The shift towards the green production technology is positive, but relatively small, such that pollution costs are hardly affected. At the same time, there is no visible effect on inflation volatility. Regarding other volatilities we observe only minor changes that we report in Table B.1 in the appendix.

Since entrepreneurs are at the heart of the transmission mechanism, we plot the model-implied means of financial market variables for different values of the green collateral parameter in Figure 5. The green and red line denote, respectively, the green and conventional entrepreneur. The welfare-maximizing green collateral parameter,  $\phi_g = 0.54$  is indicated by a vertical line. The top left panel shows that collateral premia strongly increase (i.e. the spread declines) for green entrepreneurs. Leverage increases by around one percentage points, which translates into a 50% increase in default rates. Notably the increase in collateral premia dominates the effect on corporate bond spreads, which are substantially lower despite elevated default risk.

This lowers the financing cost of green entrepreneurs, such that we observe an increase in their capital holdings of little more than 1%, which falls well short of the increase in bond issuance (2.5%). For all variables, the reaction of conventional entrepreneurs mirrors the response of their green counterparts. This is an equilibrium effect operating through the perfect substitutability of green and conventional bonds as collateral: the conventional collateral premium  $\phi_c \Omega_b$  depends on Central Bank policy and collateral supply. If green entrepreneurs increase leverage due to preferential treatment, this makes collateral less scarce, such that  $\Omega_b$  declines.

Figure 5: Simple Preferential Treatment: Financial Markets



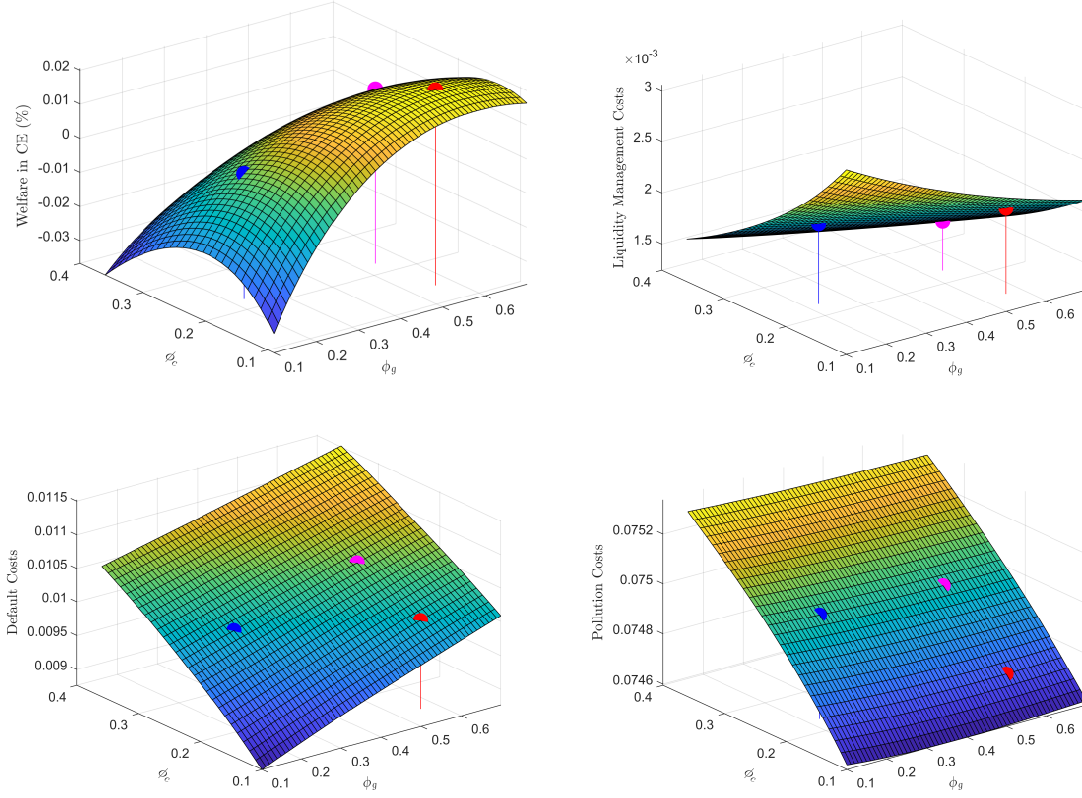
Notes: All values relative to the baseline calibration of  $\phi_{sym} = 0.23$ . Vertical line indicates optimal  $\phi_g$ .

**Optimal Collateral Policy.** While simple preferential treatment positively affects green investment shares, pollution hardly reacts. Therefore we allow for an independent variation of both collateral parameters. Optimal policy involves a tightening of the conventional collateral parameter and has a more pronounced effect on welfare. The reason is that this tightening di-

rectly reduces investment into the conventional technology. The resulting shift towards green bonds is stronger at about 0.69 percentage points. At the same time, the shift towards green capital is slightly more pronounced at about 0.32 percentage points.

The upper left plot of Figure 6 graphically illustrates the policy problem. Welfare attains its maximum at  $\phi_g = 0.56$  and  $\phi_c = 0.14$  (red dot) which exceeds welfare attained under simple preferential treatment (magenta dot). The baseline calibration is indicated by a blue dot and welfare is substantially lower in this case. All values are expressed in percentage consumption equivalents: a positive value indicates a welfare gain with respect to the baseline calibration with symmetric treatment.

Figure 6: Welfare over Collateral Policy Space



*Notes:* Blue dot represents the baseline calibration of  $\phi_{sym} = 0.23$ . Magenta dot denotes simple preferential treatment ( $\phi_c = 0.23, \phi_g = 0.52$ ), while the red dot represents the welfare optimum ( $\phi_c = 0.14, \phi_g = 0.56$ ).

We provide a welfare decomposition in the remaining panels of Figure 6. While liquidity management cost decline due to higher availability of collateral, default costs increase in  $\phi_g$ . Note that there is some curvature in liquidity management costs, suggesting that the marginal effect of collateral parameters on liquidity management costs is decreasing. On the other hand default costs increase almost proportionally. This property implies that adverse effects on finan-

cial stability become large for overly lenient green collateral parameters. Thereby, the solution to the policy problem will be interior. Notably, both cost terms increase in both collateral parameters, i.e. the cost surface exhibits substantial slant. In contrast, pollution costs strongly respond to  $\phi_c$ , since this induces conventional entrepreneurs to decrease leverage and investment.

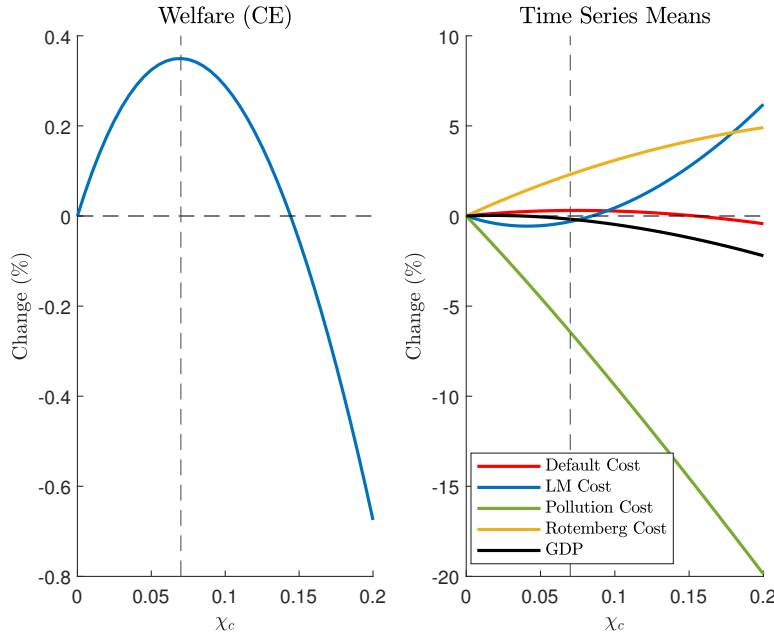
Quantitatively, we evaluate the welfare gain of optimal collateral policy to be 0.05% relative to the baseline calibration. For simple preferential treatment the welfare gain is only 0.02%. These numbers are significant when compared to the welfare losses typically obtained by similar exercises in the literature (see Lucas, 1987 and Otrok, 2001). In appendix B, we also show that nominal rigidities are not crucial drivers of our results by repeating our policy experiments (1) without Rotemberg costs and (2) with a very high Taylor rule parameter. Also, the welfare effects of collateral policy and Pigouvian taxation are of similar size.

### 4.3 Interaction with Fiscal Policy

While our analysis reveals that the Central Bank can affect the relative size of green and conventional entrepreneurs and, thereby, reduce the pollution externality, this effect is relatively small and induces non-negligible side-effects. In this section, we explore how fiscal policy can reduce pollution externalities using Pigouvian taxation. This serves a dual purpose: first, we can put the effectiveness of preferential collateral treatment into perspective, relative to Pigouvian taxation. Second, this also allows us to examine a mix of fiscal and collateral policies. By assuming a balanced budget in (22), we compare different policy instruments regarding their effectiveness to address environmental policy trade-offs without imposing assumptions on the financing of subsidies or the distribution of tax revenues.

The fourth column of Table 2 corresponds to optimal Pigouvian taxation, holding the collateral framework at its baseline value. The optimal tax on conventional production is at 7%, which implies a green subsidy of 28%. The tax tilts production towards using green inputs and reduces the pollution externality considerably, as we show in Figure 7. At the same time, this implies a deviation from the optimal input share by the wholesale goods producer, such that the economy contracts. However, the positive effects of reducing the externality exceed resource losses associated with deviating from the baseline input share, such that the optimal tax is positive. The welfare improvement of Pigouvian taxation exceeds the improvement from optimal collateral policy by a factor of 10, measured in consumption equivalents. At the same time, there are no adverse effects on firm risk-taking, since the first-order condition for leverage, (19), is not affected by a tax on production. This result suggests that fiscal instruments dominate preferential treatment when it comes to addressing environmental frictions.

Figure 7: Welfare Decomposition Under Pigouvian Taxation



Notes: Welfare relevant cost terms relative to the baseline calibration. The vertical line denotes optimal taxation.

However, this should not be misinterpreted as a call for Central Bank inaction, since fiscal policy has also a financial stability impact: changing the relative size of both sectors also affects the amount of available collateral and default risk. Crucially, the response in aggregate collateral is due to the non-linear debt choice of entrepreneurs: by the budget-neutral design of fiscal policy, the subsidy on green production is financed one-for-one by taxing conventional production. While this form of taxation does not affect leverage, it still affects the amounts of bonds issued and the investment position of both entrepreneurs. On an aggregate level, this implies that the reduced supply of conventional collateral is even exceeded by an increase in green collateral. Aggregate collateral increases relative to the baseline calibration. This, however, does not imply that this level is optimal, since taxation also has an effect on aggregate default risk. The financial stability trade-off is affected at both margins simultaneously and the effect on collateral policy is not clear a priori.

Indeed, our numerical policy experiment shows that collateral policy in the global optimum is more lenient than in the baseline calibration. When jointly optimizing over the full policy space, i.e. including the tax  $\chi_c$  and the green  $\phi_c$  and conventional  $\phi_g$  collateral parameters, we find that the Central Bank relaxes collateral treatment to restore the financial stability trade-off, as seen in column five of Table 2.<sup>20</sup> While the optimal policy mix involves a similarly-sized

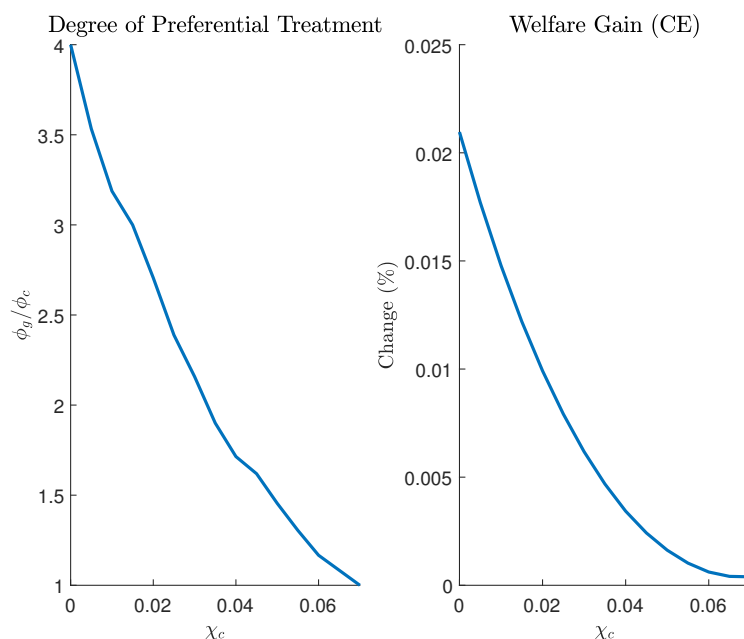
<sup>20</sup>This is similar to Carattini et al. (2021), who show that macroprudential policy can alleviate adverse effects of carbon taxation in the presence of transition risk. In their model, adverse effects take the form of asset stranding, while in our case adverse effects are linked to collateral scarcity, if conventional entrepreneurs shrink their balance sheet size. Notably, optimal macroprudential policy is also symmetric in their model.



tax of around 7%, the Central Bank increases available collateral by admitting more bonds. Importantly, the collateral parameter on both green and conventional bonds increases from 0.23 to 0.25 in a symmetric fashion. The welfare gains of adjusting collateral frameworks to mitigate collateral scarcity are positive, but of small size.

The symmetry result hinges on the assumption that optimal Pigouvian taxes are available. However, the availability of these instruments has been heavily contested by commentators and has indeed motivated Central Banks to explore their possibilities in addressing environmental concerns. In the left panel of Figure 8, we compute the optimal collateral framework, represented by the degree of preferential treatment  $\phi_g/\phi_c$ , for different levels of the Pigouvian tax. The graph starts at a ratio of four on the left, corresponding to the third column of Table 2, i.e. optimal collateral policy in the absence of taxation. At the globally optimal tax of  $\chi_c = 0.07$ , this ratio is one, indicating symmetric treatment. The right panel shows the welfare gain of optimal collateral policy, relative to the baseline collateral framework, holding the tax constant. This gain is substantial for low taxes, but diminishes as the Pigouvian tax approaches its optimum. While we are not explicit about the origin of this friction, our results indicate that Central Banks can improve on suboptimal taxation, and that the degree of preferential treatment decreases, the closer fiscal policy gets to implementing the optimal Pigouvian tax.

Figure 8: Optimal Collateral Policy Under Suboptimal Taxation



*Notes:* The left panel shows the ratio of green over conventional collateral parameters for different Pigouvian taxes. The right panel shows the relative welfare gain over the situation where collateral policy remains at its baseline value.

## 5 Yield Reaction to Central Bank Policy Announcements

So far, we analyzed the impact of preferential treatment on the corporate bond market, entrepreneurs, and investment dynamics. While the results of our policy experiments on the greenium are comparable in magnitude to the preferential treatment effect on Chinese green bonds, this observation has to be interpreted with caution due to substantial heterogeneity between China and the Euro area in general, and the monetary policy approaches of the PBoC and ECB in particular. In contrast to the PBoC’s policy, ECB communication can only be interpreted as prospect of future preferential treatment, and no details on the start date and extent of preferential treatment have been announced. Consequently, there is no direct counterpart in European bond data, which we can exploit to assess the validity of our policy experiments. Therefore, we examine how the announcements of future preferential treatment affect the model-implied greenium at the time of the announcement. To map this into our model, we draw from the news shock literature and assume that preferential treatment will be implemented with certainty, but at an unknown point in the future. We find that the model implied reaction of the greenium is of similar size as the bond market reaction to speeches of ECB board members.

**Construction of Dataset.** The first step of our analysis is to identify a list of relevant pieces of ECB communication with significant space or time devoted to environmental policy.<sup>21</sup> We do not include speeches that discuss solely *climate risk* and *transition risk*, since these refer to improving disclosure standards, the extent to which climate risk should be taken into account in credit risk assessment, and asset stranding. All these issues are important for the conduct of Central Bank policy in general, but do not specifically address bond markets. We identify two speeches by ECB board members and three speeches by ECB president Christine Lagarde. We also identify several speeches that are unrelated to Central Bank environmental policy as placebo test. The exact procedure is outlined in appendix C.

We match green and conventional bonds *one trading-day before* each announcement date using a nearest neighbours procedure. The matching is based on a score encompassing credit risk (the spread over EURIBOR-swap), liquidity risk (bid-ask spread), size (amount outstanding), and the cash-flow profile (maturity, coupon). In case even the closest conventional match obtains only for a high score, we drop the green bond at the respective date. The classification of securities into “green” and “conventional” is based on bonds listed in the “ESG” segments of *Euronext*, the *Frankfurt Stock Exchange* and the *Vienna Stock Exchange*, all of which offer publicly available lists. We limit the analysis to bonds classified as “green” or “sustainable”, which leaves us with daily market data and security characteristics of 400 green bonds. For each treatment date we have around 85 bond pairs, leaving us with a total of almost 500 observations.

<sup>21</sup>The ECB regularly publishes a dataset that contains most speeches delivered by board members and presidents.

Table C.3 contains summary statistics regarding the matching.

**Data: Yield Reaction.** At each date, we calculate the reaction of green bond yields relative to a matched control group of conventional bonds, i.e. we test whether the greenium is affected by ECB announcements. In particular, we compute the average yield difference between green bonds and their respective conventional counterparts from  $t - 20$  until  $t - 1$  as pre-treatment window and from  $t$  to  $t + 20$  as post-treatment window, where the policy announcement occurred at time  $t$ . Pre- and post-treatment windows correspond to one trading month.

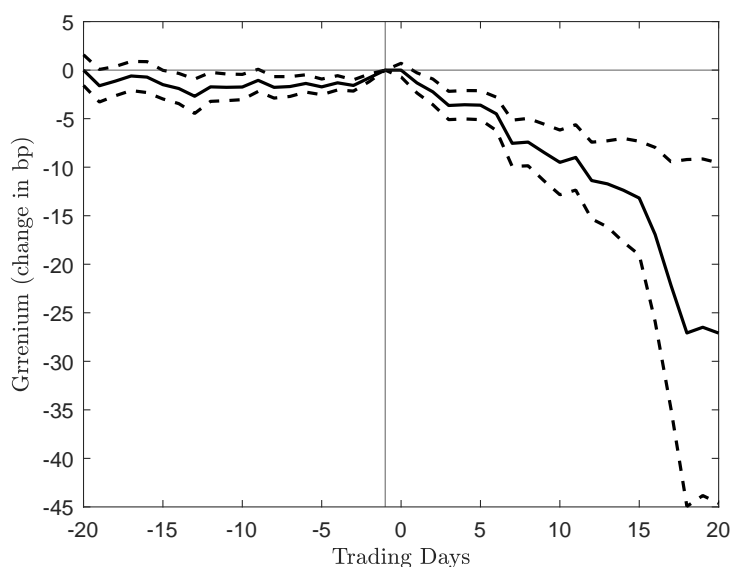


Figure 9: Average Yield Reaction around Treatment Window

*Notes:* Results are averaged over all policy announcements. Dashed lines represent 95% confidence intervals. All values in basis points.

We average the yield difference across all communication dates and plot the entire treatment window in Figure 9, controlling for pre-trends. Averaging over all announcements and the entire post-treatment window, the announcement effect is significant in statistical terms: after each ECB announcement, green bond yields drop by 9.3bp on average over a twenty trading day window. The change of the greenium is significant two days after the announcement and widens to 25bp twenty trading days after the announcement date. This is economically meaningful and lies in a plausible range, compared to the empirical literature on collateral premia of corporate bonds. The result indicates that bond market investors are willing to pay premia on green bonds, if there is the prospect of preferential treatment.<sup>22</sup>

<sup>22</sup>This decline of the greenium could be driven by investor preferences for sustainability. To exclude this possibil-

**Model-Implied Yield Reaction.** To map these announcements into our model, we draw on the literature on news shocks (Beaudry and Portier, 2004; Barsky and Sims, 2011). Specifically, we enrich the baseline calibration to a news shock to the green collateral parameter  $\phi_g$  for various time horizons. The shock size is set such that  $\phi_g$  attains its value under simple preferential treatment ( $\phi_g = 0.52$ ) in three, five, or seven years. These horizons appear plausible, given that the ECB strategy review itself already takes around two years and that the actual implementation of preferential treatment takes time to prepare. In the model, anticipation of preferential treatment is linked to the green collateral parameter  $\phi_g$ . Rather than setting the collateral framework to a constant, we impose a persistent log-AR(1) process on the green collateral parameter

$$\log(\phi_{g,t}) = \log(\phi_{sym}) + \sigma_\phi \varepsilon_{t-h}^\phi \quad \varepsilon_{t-h}^\phi \sim N(0, 1) , \quad (38)$$

where  $\phi_{sym}$  is the green collateral parameter corresponding to the baseline calibration and  $h$  denotes the announcement horizon. The shock standard deviation is set such that it implies preferential treatment in period  $t + h$

$$\sigma_\phi = \log(\phi_g^* | \phi_c = \phi_{sym}) - \log(\phi_{sym}) . \quad (39)$$

Since the ECB so far did not announce a date after which preferential treatment may be applied, we compute values for different announcement horizons in Table 3: three, five, and seven years.

Table 3: Greenium Reaction: Data vs Model

Data	Model: Horizon			
	1 year	3 years	5 years	7 years
-9.3bp	-18.0bp	-10.8bp	-6.5bp	-3.9bp

The announcement effect in the model, as measured by the greenium, lies between -3.9bp and -18bp, depending on the time horizon. A more near-term announcement induces a stronger effect since collateral benefits are priced via the bond continuation value. The shorter the horizon, the less the preferential treatment is discounted. In the three-year-specification, the greenium is -10.8bp on impact, which closely resembles the average effect over all announcement dates and post-treatment days we find in the data (-9.3bp). Arguably, the three-year-horizon seems realistic in case the ECB plans to adapt its collateral framework since it is both sufficiently

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ity, the analysis is based on relatively high frequency observations where it is reasonable to assume that investor preferences remain constant. We also provide supporting evidence by examining the impact of environmental performance scores on corporate bond spreads in appendix D and find no significant effect.

long-term to work out details but also not too much in the future to miss the current public sentiment to gain support for such a step. We interpret the close fit of our model implication and the data estimate as an additional external validity check of our numerical policy experiments.

## 6 Conclusion

In this paper, we examine preferential collateral treatment of green bonds, which is a candidate instrument Central Banks can use to address environmental concerns. Preferential treatment stimulates investment into green bonds. However, the increased investment into green bonds only partially transmits to real investment into green technologies due to an increase in green entrepreneurs' leverage and higher default risk. This adverse effect on aggregate financial stability can be addressed by using a tightening of collateral treatment for conventional bonds, which keeps the aggregate amount of collateral and default risk constant. Further, we consider fiscal policy addressing environmental concerns through direct Pigouvian taxation. This policy is most effective in reducing environmental damage, but also implies a decrease in available collateral that is necessary for banks' short-term borrowing. The Central Bank adjusts the collateral framework to alleviate collateral scarcity *without* preferential treatment. However, when fiscal policy is unable to implement the optimal tax, there is scope for preferential collateral treatment to support fiscal policy in shifting the economy towards green technologies.

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## A Model Appendix

### A.1 Final Goods Producers

Each final goods firm  $i$  maximizes the expected sum of discounted profits:

$$\max_{P_{i,t}, y_{i,t}} \mathbb{E}_0 \left[ \sum_{t=0}^{\infty} \beta^t \frac{\lambda_t}{\lambda_0} \left( P_{i,t} y_{i,t} - mc_t P_t y_{i,t} - \frac{\psi}{2} \left( \frac{P_{i,t}}{P_{i,t-1}} - 1 \right)^2 P_t y_t \right) \right],$$

subject to

$$y_{i,t} = \left( \frac{P_{i,t}}{P_t} \right)^{-\varepsilon} y_t.$$

Plugging in the demand function

$$\max_{P_{i,t}} \mathbb{E}_0 \left[ \sum_{s=0}^{\infty} \beta^s \frac{\lambda_s}{\lambda_0} \left( (P_{i,t} - mc_t P_t) \left( \frac{P_{i,t}}{P_t} \right)^{-\varepsilon} y_t - \frac{\psi}{2} \left( \frac{P_{i,t}}{P_{i,t-1}} - 1 \right)^2 P_t y_t \right) \right],$$

yields the first-order condition

$$\begin{aligned} & \left( \frac{P_{i,t}}{P_t} \right)^{-\varepsilon} Y_t - \varepsilon (P_{i,t} - mc_t P_t) \left( \frac{P_{i,t}}{P_t} \right)^{-\varepsilon} \frac{y_t}{P_t} - \psi \left( \frac{P_{i,t}}{P_{i,t-1}} - 1 \right) \frac{P_t}{P_{i,t-1}} y_t \\ & + \mathbb{E}_t \left[ \frac{\lambda_{t+1}}{\lambda_t} \psi \left( \frac{P_{i,t+1}}{P_{i,t}} - 1 \right) \frac{P_{i,t+1}}{P_{i,t}^2} P_{t+1} y_{t+1} \right] = 0. \end{aligned}$$



In a symmetric price equilibrium,  $P_{i,t} = P_t$  for all  $i$ . Using this, we rearrange and get

$$(1 - \varepsilon(1 - mc_t))y_t + \mathbb{E}_t \left[ \beta \frac{\lambda_{t+1}}{\lambda_t} y_{t+1} \pi_{t+1} \psi(\pi_{t+1} - 1) \pi_{t+1} \right] = \psi(\pi_t - 1) \pi_t y_t ,$$

where  $\pi_t = \frac{P_t}{P_{t-1}}$ . Dividing both sides by  $y_t$  and  $\phi$  we arrive at the New Keynesian Phillips Curve

$$\mathbb{E}_t \left[ \beta \frac{\lambda_{t+1}}{\lambda_t} \frac{y_{t+1} \pi_{t+1}}{y_t} (\pi_{t+1} - 1) \pi_{t+1} \right] + \frac{\varepsilon}{\psi} (mc_t - mc^*) = (\pi_t - 1) \pi_t ,$$

where  $mc^* \equiv \frac{\varepsilon - 1}{\varepsilon}$ .

## A.2 Entrepreneur Problem

We start with observing that the default threshold of a type  $\tau$ -entrepreneur in period  $t + 1$  is given by  $\bar{m}_{\tau,t+1} \equiv \frac{sb_{\tau,t+1}}{\pi_{t+1}(1-\chi_\tau)p_{\tau,t+1}k_{\tau,t+1}}$  such that an entrepreneur with  $m < \bar{m}_{\tau,t+1}$  defaults. Note that the following properties hold:

$$\frac{\partial \bar{m}_{\tau,t+1}}{\partial b_{\tau,t+1}} = \frac{s}{\pi_{t+1}(1-\chi_\tau)p_{\tau,t+1}k_{\tau,t+1}} = \frac{b_{\tau,t+1}}{\pi_{t+1}(1-\chi_\tau)p_{\tau,t+1}k_{\tau,t+1}} \frac{s}{b_{\tau,t+1}} = \frac{\bar{m}_{\tau,t+1}}{b_{\tau,t+1}} \quad (\text{A.1})$$

$$\frac{\partial \bar{m}_{\tau,t+1}}{\partial k_{\tau,t+1}} = -\frac{sb_{\tau,t+1}}{\pi_{t+1}(1-\chi_\tau)p_{\tau,t+1}k_{\tau,t+1}^2} = -\frac{b_{\tau,t+1}}{\pi_{t+1}(1-\chi_\tau)p_{\tau,t+1}k_{\tau,t+1}} \frac{s}{k_{\tau,t+1}} = -\frac{\bar{m}_{\tau,t+1}}{k_{\tau,t+1}} . \quad (\text{A.2})$$

We assume that  $\log(m)$  is normally distributed with mean  $\mu_M$  and standard deviation  $\sigma_M$ . In the calibration, we ensure that  $\mathbb{E}[m] = 1$  by setting  $\mu_M = -\frac{\sigma_M^2}{2}$ . The CDF of  $m$  is given by  $F(m) = \Phi\left(\frac{\log m - \mu_M}{\sigma_M}\right)$ , where  $\Phi(\cdot)$  is the cdf of the standard normal distribution. The conditional mean of  $m$  at the threshold value  $\bar{m}_{\tau,t+1}$  can be expressed as

$$G(\bar{m}_{\tau,t+1}) = \int_0^{\bar{m}_{\tau,t+1}} mf(m)dm = e^{\mu_M + \frac{\sigma_M^2}{2}} \Phi\left(\frac{\log \bar{m}_{\tau,t+1} - \mu_M - \sigma_M^2}{\sigma_M}\right) ,$$

$$1 - G(\bar{m}_{\tau,t+1}) = \int_{\bar{m}_{\tau,t+1}}^\infty mf(m)dm = e^{\mu_M + \frac{\sigma_M^2}{2}} \Phi\left(\frac{-\log \bar{m}_{\tau,t+1} + \mu_M + \sigma_M^2}{\sigma_M}\right) .$$

Note that

$$G'(\bar{m}_{\tau,t+1}) = \bar{m}_{\tau,t+1} F'(\bar{m}_{\tau,t+1}) . \quad (\text{A.3})$$

For notational convenience, we write the bond price schedule as function of the default threshold  $\bar{m}_{\tau,t}$  throughout this section. The nominal bond payoff is given by

$$\mathcal{R}_{\tau,t} = s \left( G(\bar{m}_{\tau,t}) \frac{\pi_t(1-\chi_\tau)p_{\tau,t}k_{\tau,t}}{sb_{\tau,t}} + 1 - F(\bar{m}_{\tau,t}) \right) - F(\bar{m}_{\tau,t})\varphi + (1-s)q_{\tau,t},$$

such that we can write the bond price only in terms of the default threshold  $\bar{m}_{\tau,t+1}$

$$q(\bar{m}_{\tau,t+1}) = \frac{s \left( \frac{G(\bar{m}_{\tau,t+1})}{\bar{m}_{\tau,t+1}} + 1 - F(\bar{m}_{\tau,t+1}) \right) - F(\bar{m}_{\tau,t+1})\varphi + (1-s)q_{\tau,t+1}}{(1 + \phi_\tau \Omega_{b,t})(1 + i_t^D)}. \quad (\text{A.4})$$

The derivative with respect to the default threshold is given by

$$q'(\bar{m}_{\tau,t+1}) = \frac{-\frac{sG(\bar{m}_{\tau,t+1})}{\bar{m}_{\tau,t+1}^2} - \varphi F'(\bar{m}_{\tau,t+1})}{(1 + \phi_\tau \Omega_{b,t})(1 + i_t^D)}. \quad (\text{A.5})$$

The type- $\tau$  entrepreneur maximization problem reads

$$V^E(b_{\tau,t}, k_{\tau,t}) = \max_{b_{\tau,t+1}, k_{\tau,t+1}} \tilde{c}_{\tau,t} + \tilde{\beta} \mathbb{E}_t [V^E(b_{\tau,t+1}, k_{\tau,t+1})],$$

where entrepreneur's consumption is given by

$$\begin{aligned} \tilde{c}_{\tau,t} = & (1 - G(\bar{m}_{\tau,t}))(1 - \chi_\tau)p_{\tau,t}k_{\tau,t} - (1 - F(\bar{m}_{\tau,t}))sb_{\tau,t} - k_{\tau,t+1} + (1 - \delta)k_{\tau,t} \\ & + q(\bar{m}_{\tau,t}) \left( b_{\tau,t+1} - (1 - s)\frac{b_{\tau,t}}{\pi_t} \right). \end{aligned}$$

Under the assumption of no delays in restructuring and i.i.d. productivity shocks, the problem boils down to a two-period consideration

$$\begin{aligned} \max_{k_{\tau,t+1}, b_{\tau,t+1}} & -k_{\tau,t+1} + q(\bar{m}_{\tau,t}) \left( b_{\tau,t+1} - (1 - s)\frac{b_{\tau,t}}{\pi_t} \right) \\ & + \tilde{\beta} \left[ (1 - G(\bar{m}_{\tau,t+1}))(1 - \chi_\tau)p_{\tau,t+1}k_{\tau,t+1} + (1 - \delta)k_{\tau,t+1} \right. \\ & \quad \left. - s(1 - F(\bar{m}_{\tau,t+1}))\frac{b_{\tau,t+1}}{\pi_{t+1}} + q_{\tau,t+1} \left( b_{\tau,t+1} - (1 - s)\frac{b_{\tau,t}}{\pi_{t+1}} \right) \right], \end{aligned}$$

for an arbitrary continuation value of bonds  $q_{\tau,t+1}$ .

**FOC w.r.t  $b_{\tau,t+1}$**  The first-order condition for bonds is then given by

$$0 = \left[ q'(\bar{m}_{\tau,t+1}) \frac{\partial \bar{m}_{t+1}}{\partial b_{\tau,t+1}} \left( b_{\tau,t+1} - (1-s) \frac{b_{\tau,t}}{\pi_t} \right) + q(\bar{m}_{\tau,t+1}) \right] \\ + \tilde{\beta} \left[ -(1-\chi_\tau) p_{\tau,t+1} k_{\tau,t+1} G'(\bar{m}_{\tau,t+1}) \frac{\partial \bar{m}_{\tau,t+1}}{\partial b_{\tau,t+1}} \right. \\ \left. - \frac{s}{\pi_{t+1}} \left( -F'(\bar{m}_{\tau,t+1}) \frac{\partial \bar{m}_{\tau,t+1}}{\partial b_{\tau,t+1}} b_{\tau,t+1} + 1 - F(\bar{m}_{\tau,t+1}) \right) - q_{\tau,t+1} \frac{1-s}{\pi_{t+1}} \right],$$

which can be expressed as

$$0 = \left[ q'(\bar{m}_{\tau,t+1}) \frac{\bar{m}_{\tau,t+1}}{b_{\tau,t+1}} \left( b_{\tau,t+1} - (1-s) \frac{b_{\tau,t}}{\pi_t} \right) + q(\bar{m}_{\tau,t+1}) \right] \\ + \tilde{\beta} \left[ -\frac{s}{\pi_{t+1}} G'(\bar{m}_{\tau,t+1}) \frac{\bar{m}_{\tau,t+1} (1-\chi_\tau) p_{\tau,t+1} k_{\tau,t+1} \pi_{t+1}}{s b_{\tau,t+1}} \right. \\ \left. - \frac{s}{\pi_{t+1}} \left( -F'(\bar{m}_{\tau,t+1}) \bar{m}_{\tau,t+1} + 1 - F(\bar{m}_{\tau,t+1}) \right) - q_{\tau,t+1} \frac{1-s}{\pi_{t+1}} \right],$$

and then yields (19). Plugging in  $q'(\bar{m}_{\tau,t+1})$  and  $q(\bar{m}_{\tau,t+1})$ , we have

$$0 = \frac{1}{(1+\phi_\tau \Omega_{b,t})(1+i_t^D)} \left[ s \left( G'(\bar{m}_{\tau,t+1}) - \frac{G(\bar{m}_{\tau,t+1})}{\bar{m}_{\tau,t+1}} - F'(\bar{m}_{\tau,t+1}) \bar{m}_{\tau,t+1} \right) \right. \\ \left. - \phi F'(\bar{m}_{\tau,t+1}) \bar{m}_{\tau,t+1} \right] \frac{b_{\tau,t+1} - (1-s) \frac{b_{\tau,t}}{\pi_t}}{b_{\tau,t+1}} \\ + \frac{1}{(1+\phi_\tau \Omega_{b,t})(1+i_t^D)} \left[ s \left( \pi_{t+1} \frac{G(\bar{m}_{\tau,t+1})}{\bar{m}_{\tau,t+1}} + 1 - F(\bar{m}_{\tau,t+1}) \right) - \phi F(\bar{m}_{\tau,t+1}) + (1-s) q_{t+1} \right] \\ + \tilde{\beta} \left[ -\frac{s}{\pi_{t+1}} \left( G'(\bar{m}_{\tau,t+1}) - F'(\bar{m}_{\tau,t+1}) \bar{m}_{\tau,t+1} + 1 - F(\bar{m}_{\tau,t+1}) \right) - q_{\tau,t+1} \frac{1-s}{\pi_{t+1}} \right].$$

Now, using  $G'(\bar{m}_{\tau,t+1}) = \bar{m}_{\tau,t+1} F'(\bar{m}_{\tau,t+1})$ , we can rearrange to obtain

$$\frac{s}{(1+\phi_\tau \Omega_{b,t})(1+i_t^D)} \frac{(1-s) \frac{b_{\tau,t}}{\pi_{t+1}}}{b_{\tau,t+1}} \frac{G(\bar{m}_{\tau,t+1})}{\bar{m}_{t+1}} \\ + \left( \frac{1}{(1+\phi_\tau \Omega_{b,t})(1+i_t^D)} - \frac{\tilde{\beta}}{\pi_{t+1}} \right) s (1 - F(\bar{m}_{\tau,t+1})) \\ + \left( \frac{1}{(1+\phi_\tau \Omega_{b,t})(1+i_t^D)} - \frac{\tilde{\beta}}{\pi_{t+1}} \right) q_{t+1} (1-s) \\ = \frac{\phi}{(1+\phi_\tau \Omega_{b,t})(1+i_t^D)} \left( F'(\bar{m}_{\tau,t+1}) \bar{m}_{\tau,t+1} \frac{b_{\tau,t+1} - (1-s) \frac{b_{\tau,t}}{\pi_t}}{b_{\tau,t+1}} + F(\bar{m}_{\tau,t+1}) \right).$$

**FOC w.r.t  $k_{\tau,t+1}$**  The first-order condition for capital is

$$1 = q'(\bar{m}_{\tau,t+1}) \frac{\partial \bar{m}_{\tau,t+1}}{\partial k_{\tau,t+1}} \left( b_{\tau,t+1} - (1-s) \frac{b_{\tau,t}}{\pi_t} \right) \\ + \tilde{\beta} \left[ -G'(\bar{m}_{\tau,t+1}) \frac{\partial \bar{m}_{\tau,t+1}}{\partial k_{\tau,t+1}} (1 - \chi_{\tau}) p_{\tau,t+1} k_{\tau,t+1} + (1 - G(\bar{m}_{\tau,t+1})) p_{\tau,t+1} \right. \\ \left. + \frac{s}{\pi_{t+1}} b_{\tau,t+1} F'(\bar{m}_{\tau,t+1}) \bar{m}_{\tau,t+1} \frac{\partial \bar{m}_{\tau,t+1}}{\partial k_{\tau,t+1}} + 1 - \delta \right],$$

which can be rearranged to

$$1 - \tilde{\beta}(1 - \delta) = -q'(\bar{m}_{\tau,t+1}) \frac{\bar{m}_{\tau,t+1}}{k_{\tau,t+1}} \left( b_{\tau,t+1} - (1-s) \frac{b_{\tau,t}}{\pi_t} \right) \\ + \tilde{\beta} \left[ G'(\bar{m}_{\tau,t+1}) \bar{m}_{\tau,t+1} p_{\tau,t+1} + (1 - G(\bar{m}_{\tau,t+1})) p_{\tau,t+1} \right. \\ \left. - \frac{s}{\pi_{t+1}} b_{\tau,t+1} F'(\bar{m}_{\tau,t+1}) \frac{\bar{m}_{\tau,t+1}}{k_{\tau,t+1}} \frac{p_{\tau,t+1}}{p_{\tau,t+1}} \right],$$

and further to (20).

## B Numerical Appendix

Table B.1 provides the time series volatilities from our main policy experiments, supplementing the time series means from Table 2. Compared to the change in time series means, the effect on time series volatilities is relatively small through all policy experiments. The green bond and capital shares are constant whenever the collateral framework is symmetric, since the TFP shock affects the final goods producer and both entrepreneurs choose the same level of risk.

Table B.1: Time Series Volatilities

Moment	Baseline	Simple Pref	Optimal Coll	Simple Tax	Glob Optimum
Tax Parameter $\chi_c$	0	0	0	0.07	0.07
Coll. Parameter $\phi_g$	0.23	0.54	0.56	0.23	0.25
Coll. Parameter $\phi_c$	0.23	0.23	0.15	0.23	0.25
Conv. Bonds	0.052	0.052	0.053	0.048	0.048
Green Bonds	0.013	0.012	0.012	0.017	0.017
Conv. Leverage	0.39%	0.38%	0.41%	0.39%	0.39%
Green Leverage	0.39%	0.36%	0.38%	0.39%	0.39%
Conv. Bond Spread	69bp	67bp	68bp	70bp	70bp
Green Bond Spread	69bp	69bp	72bp	70bp	70bp
Conv. Coll. Premium	0.3bp	0.3bp	0.2bp	0.3bp	0.3bp
Green Coll. Premium	0.3bp	0.6bp	0.7bp	0.3bp	0.3bp
Green Bond Share	0%	0.04%	0.06%	0%	0%
Green Capital Share	0%	0.02%	0.04%	0%	0%

To gauge the importance of nominal rigidities, we repeat our policy experiments (1) without Rotemberg costs and (2) with a Taylor-rule parameter of 50, i.e. interest rate policy is extremely sensitive to inflation. The first case is reported in Table B.2 and shows very similar collateral policy implications. Results for the second case are shown in Table B.3

Table B.2: Time Series Means with  $\psi = 0$ 

Moment	Baseline	Simple Pref	Optimal Coll	Simple Tax	Glob Optimum
Tax Parameter $\chi_c$	0	0	0	0.07	0.07
Coll. Parameter $\phi_g$	0.23	0.54	0.57	0.23	0.245
Coll. Parameter $\phi_c$	0.23	0.23	0.14	0.23	0.245
Welfare Change (CE)	0%	0.014%	0.021%	0.352%	0.353%
Conv. Bonds	1.909	1.905	1.889	1.781	1.784
Green Bonds	0.477	0.489	0.493	0.613	0.613
Conv. Leverage	39.1%	39.1%	89.9%	39.2%	39.2%
Green Leverage	39.1%	39.6%	39.8%	39.2%	39.2%
Conv. Bond Spread	100bp	104bp	116bp	100bp	99bp
Green Bond Spread	100bp	57bp	41bp	100bp	99bp
Conv. Coll. Premium	-7bp	-6bp	-4bp	-7bp	-7bp
Green Coll. Premium	-7bp	-15bp	-18bp	-7bp	-7bp
GDP	0.7455	0.7462	0.7456	0.7442	0.7444
Rotemberg Cost	0	0	0	0	0
Default Cost	0.0100	0.0105	0.0101	0.0100	0.0102
Liquidity Management Cost	0.0010	0.0007	0.0010	0.0010	0.0010
Pollution Cost	0.0750	0.0749	0.0747	0.0701	0.0702
Green Bond Share	20.00%	20.44%	20.70%	25.60%	25.60%
Green Capital Share	20.00%	20.21%	20.33%	25.60%	25.60%

Table B.3: Time Series Means with  $\phi_\pi = 50$ 

Moment	Baseline	Simple Pref	Optimal Coll	Simple Tax	Glob Optimum
Tax Parameter $\chi_c$	0	0	0	0.07	0.07
Coll. Parameter $\phi_g$	0.23	0.53	0.56	0.23	0.25
Coll. Parameter $\phi_c$	0.23	0.23	0.15	0.23	0.25
Welfare Change (CE)	0%	0.014%	0.02%	0.353%	0.353%
Conv. Bonds	1.901	1.905	1.891	1.781	1.784
Green Bonds	0.477	0.489	0.492	0.613	0.614
Conv. Leverage	39.2%	39.1%	39.0%	39.2%	39.2%
Green Leverage	39.2%	39.7%	39.8%	39.2%	39.2%
Conv. Bond Spread	99bp	104bp	114bp	100bp	98bp
Green Bond Spread	99bp	58bp	43bp	100bp	98bp
Conv. Coll. Premium	-7bp	-6bp	-5bp	-7bp	-8bp
Green Coll. Premium	-7bp	-15bp	-17bp	-7bp	-8bp
GDP	0.7455	0.7462	0.7456	0.7441	0.7443
Rotemberg Cost	0	0	0	0	0
Default Cost	0.0100	0.0105	0.0100	0.0100	0.0102
Liquidity Management Cost	0.0009	0.0006	0.0009	0.0009	0.0008
Pollution Cost	0.0750	0.0749	0.0747	0.0701	0.0702
Green Bond Share	20.00%	20.43%	20.66%	25.60%	25.60%
Green Capital Share	20.00%	20.21%	20.31%	25.60%	25.60%

In Table B.4 and Table B.5 we provide robustness checks regarding the optimal policy experiments. We focus on the Cobb-Douglas parameters of wholesale goods producers  $v$  and the externality parameter  $\gamma_p$ , since these two parameters govern the environmental side of our model. To ensure an apples-to-apples comparison, we recalibrate the parameter  $\eta_0$  governing the strength of the risk-externality, such that the collateral parameter under symmetry  $\phi_{sym}$  is optimal with respect to the welfare objective.

Reducing the externality parameter to  $\gamma_p = 7.5e - 03$  reflects a situation with a relatively low impact of pollution on aggregate TFP. The recalibrated risk externality slope is  $\eta_0 = 85$ . Since the pollution externality is smaller in this setting, both the optimal Pigouvian tax and optimal preferential treatment are smaller than in the baseline calibration.

Table B.4: Time Series Means with  $\gamma_P = 7.5e - 03$ 

Moment	Baseline	Simple Pref	Optimal Coll	Simple Tax	Glob Optimum
Tax Parameter $\chi_c$	0	0	0	0.035	0.035
Coll. Parameter $\phi_g$	0.23	0.38	0.39	0.23	0.23
Coll. Parameter $\phi_c$	0.23	0.23	0.18	0.23	0.23
Welfare Change (CE)	0%	0.004%	0.006%	0.096%	0.096%
Conv. Bonds	2.017	2.015	2.006	1.948	1.948
Green Bonds	0.504	0.511	0.513	0.575	0.575
Conv. Leverage	39.1%	39.1%	39.0%	39.1%	39.1%
Green Leverage	39.1%	39.4%	39.5%	39.1%	39.1%
Conv. Bond Spread	102bp	104bp	111bp	102bp	102bp
Green Bond Spread	102bp	80bp	73bp	102bp	102bp
Conv. Coll. Premium	-7bp	-7bp	-6bp	-7bp	-7bp
Green Coll. Premium	-7bp	-11bp	-12bp	-7bp	-7bp
GDP	0.7506	0.7607	0.7611	0.7607	0.7604
Rotemberg Cost	6.8e-05	6.7e-05	6.8e-05	6.8e-05	6.8e-05
Default Cost	0.0106	0.0108	0.0105	0.0106	0.0106
Liquidity Management Cost	0.0040	0.0040	0.0034	0.0034	0.0034
Pollution Cost	0.0404	0.0404	0.0403	0.0390	0.0390
Green Bond Share	20.00%	20.24%	20.36%	22.80%	22.80%
Green Capital Share	20.00%	20.10%	20.16%	22.80%	22.80%



Table B.5: Time Series Means with  $\nu = 0.4$ 

Moment	Baseline	Simple Pref	Optimal Coll	Simple Tax	Glob Optimum
Tax Parameter $\chi_c$	0	0	0	0.115	0.115
Coll. Parameter $\phi_g$	0.23	0.41	0.42	0.23	0.25
Coll. Parameter $\phi_c$	0.23	0.23	0.10	0.23	0.25
Welfare Change (CE)	0%	0.012%	0.026%	0.447%	0.448%
Conv. Bonds	1.360	1.357	1.338	1.209	1.210
Green Bonds	0.907	0.920	0.925	1.068	1.069
Conv. Leverage	39.2%	39.1%	38.9%	39.2%	39.2%
Green Leverage	39.2%	39.5%	39.6%	39.2%	39.2%
Conv. Bond Spread	99bp	105bp	123bp	99bp	98bp
Green Bond Spread	99bp	76bp	66bp	99bp	98bp
Conv. Coll. Premium	-8bp	-7bp	-3bp	-7bp	-8bp
Green Coll. Premium	-8bp	-12bp	-13bp	-7bp	-8bp
GDP	0.6972	0.6936	0.6929	0.6915	0.6917
Rotemberg Cost	5.8e-05	5.8e-05	5.8e-05	6.0e-05	6.0e-05
Default Cost	0.0097	0.0102	0.0097	0.0097	0.0098
Liquidity Management Cost	0.0023	0.0020	0.0024	0.0023	0.0022
Pollution Cost	0.0540	0.0540	0.0537	0.0482	0.0482
Green Bond Share	40.00%	40.41%	40.87%	46.90%	46.90%
Green Capital Share	40.00%	40.18%	40.37%	46.90%	46.90%

While we used TFP shocks in the baseline simulation, we repeat our policy experiments under the assumption that entrepreneurs idiosyncratic risk is stochastic as a third robustness check. Following Christiano et al. (2014), we assume that the variance of idiosyncratic productivity follows an AR(1) process in logs

$$\log(\zeta_{M,t+1}) = (1 - \rho_M) \log(\zeta_{M,ss}) + \rho_M \log(\zeta_{M,t}) + \sigma_M \varepsilon_{t+1}^M, \quad \varepsilon_{t+1}^M \sim N(0, 1). \quad (\text{A.6})$$

The results, shown in Table B.6, are again very similar to the baseline results reported in Table 2.

Table B.6: Time Series Means with Risk Shocks

Moment	Baseline	Simple Pref	Optimal Coll	Simple Tax	Glob Optimum
Tax Parameter $\chi_c$	0	0	0	0.07	0.07
Coll. Parameter $\phi_g$	0.23	0.56	0.58	0.23	0.26
Coll. Parameter $\phi_c$	0.23	0.23	0.15	0.23	0.26
Welfare Change (CE)	0%	0.016%	0.021%	0.35%	0.35%
Conv. Bonds	1.908	1.905	1.891	1.781	1.784
Green Bonds	0.477	0.490	0.493	0.613	0.614
Conv. Leverage	39.1%	39.0%	38.9%	39.3%	39.0%
Green Leverage	39.1%	39.6%	39.7%	39.3%	39.7%
Conv. Bond Spread	102bp	109bp	116bp	92bp	108bp
Green Bond Spread	102bp	66bp	59bp	92bp	49bp
Conv. Coll. Premium	-7bp	-6bp	-5bp	-9bp	-7bp
Green Coll. Premium	-7bp	-14bp	-15bp	-9bp	-17bp
GDP	0.7506	0.7510	0.7506	0.6477	0.6701
Rotemberg Cost	5.7e-05	5.7e-05	5.7e-05	5.9e-05	5.8e-05
Default Cost	0.0101	0.0106	0.0102	0.0101	0.0104
Liquidity Management Cost	0.0019	0.0016	0.0019	0.0019	0.0018
Pollution Cost	0.0750	0.0750	0.0748	0.0702	0.0702
Green Bond Share	20.00%	20.47%	20.68%	25.60%	25.60%
Green Capital Share	20.00%	20.22%	20.32%	25.60%	25.60%

## C Data Appendix

Table C.1 summarizes the data sources on which our empirical analysis is based. The classification of bonds as "green" is based on publicly available lists of securities traded via various stock exchanges. Based on the list of ISINs, we retrieve bond-specific info from Datastream. Data on conventional bonds in the control group is taken from Markit. EURIBOR data are obtained through Datastream.

Table C.1: Data Sources and Ticker

Series	Source	Mnemonic
Green Bond List I	Euronext	<a href="#">List</a> retrieved Nov-30-2020
Green Bond List II	FSE	<a href="#">List</a> retrieved Nov-30-2020
Green Bond List III	Vienna FSE	<a href="#">List</a> retrieved Nov-30-2020
Constant Maturity Ask Price	Datastream	CMPA
Constant Maturity Bid Price	Datastream	CMPB
Coupon	Datastream	C
Issue Date	Datastream	ID
Amount Outstanding	Datastream	AOS
Currency	Datastream	PCUR
Life At Issue	Datastream	LFIS
Redemption Date	Datastream	RD
EURIBOR rates (... with maturity)	Datastream	TRE6S...Y

To identify relevant speeches for our empirical analysis, we rely on a dataset published by the ECB that contains date, title (including sub-titles in the format "TYPE by SPEAKER, ROLE, at OCCASION"), speaker and content as well as footnotes of nearly all speeches by presidents and board members since 1999.<sup>23</sup> We perform the following steps:

- We string-match titles and content separately for the following keywords: climate, green, sustainable, greenhouse, environment, warming, climatic, carbon, coal.
- We designate a speech for manual inspection as soon as we have one match for a title or three matches for content (variations did not change results).
- We exclude a speech if insufficient space is devoted to the topic, there is no monetary policy relation, or if we have a wrong positive (e.g. *environment* refers to low interest rates or inflation).
- We exclude speeches that address climate risk or transition risk.
- All speeches within 20 trading days of the previous speech are excluded to avoid overlapping treatment periods.

One speech was followed a press release published via Reuters on the subsequent trading day regarding an explicit announcement of preferential treatment. We do not include communication that refer to *climate risk* and *transition risk*, since these refer to improving disclosure

<sup>23</sup>See European Central Bank (2021). Speeches dataset. Retrieved from: <https://www.ecb.europa.eu/press/key/html/downloads.en.html>.

standards, the extent to which climate risk should be taken into account in credit risk assessment, and asset stranding. All these issues are important for the conduct of Central Bank policy in general, but do not specifically address bond markets. This leaves us with five speeches. Table C.2 contains details regarding the key content that motivate our classification.

Table C.2: Relevant ECB Policy Announcements

Date	Type	Link	Relevant Quotes
08-11-2018	Benoît Cœuré	<a href="#">ECB</a>	<ul style="list-style-type: none"> <li>(...) the ECB, acting within its mandate, can – and should – actively support the transition to a low carbon economy (...) second, by acting accordingly, without prejudice to price stability.</li> <li>Purchasing green bonds (...) could be an option, as long as the markets are deep and liquid enough.</li> </ul>
05-02-2020	Christine Lagarde	<a href="#">ECB</a>	<ul style="list-style-type: none"> <li>In keeping with this, climate change will be a key part of our ongoing strategy review.</li> <li>(...) bringing climate change more fundamentally into our analysis and strategy (...) climate change is also a price stability risk.</li> </ul>
27-02-2020	Christine Lagarde	<a href="#">ECB</a>	<ul style="list-style-type: none"> <li>(...) reviewing the extent to which climate-related risks are understood and priced by the market (...)</li> <li>(...) evaluate the implications for our own management of risk, in particular through our collateral framework.</li> </ul>
17-07-2020	Isabel Schnabel	<a href="#">ECB</a>	<ul style="list-style-type: none"> <li>(...) way in which we can contribute is by taking climate considerations into account when designing and implementing our monetary policy operations.</li> <li>(...) Of course, Central Banks would need to be mindful of their effects on market functioning.</li> <li>(...) severe risks to price stability, Central Banks are required, within their traditional mandates, to strengthen their efforts (...)</li> </ul>
21-09-2020	Christine Lagarde	<a href="#">ECB</a>	<ul style="list-style-type: none"> <li>We cannot miss this opportunity to reduce and prevent climate risks and finance the necessary green transition.</li> <li>The ECB's ongoing strategy review will ensure that its monetary policy strategy is fit for purpose (...)</li> <li>(...) Jean Monnet's words, (...) opportunity for Europe to take a step towards the forms of organisation of the world of tomorrow.</li> <li>On 22-09-2020, <a href="#">Reuters</a> reported that sustainability-linked bonds will be added to the list of eligible collateral at some unspecified date.</li> </ul>

Since many green bonds do not show up in the *IHS Markit* database, we additionally obtain data from *Thomson Reuters Datastream*. From this dataset, we identify an appropriate untreated bond as control group, which is the conventional bond with the smallest distance to the green bond. We drop a green bond if the distance to the closest conventional bond is too high. Table C.3 contains summary statistics regarding the matching. While coupon and bid-ask spreads are very similar for both types of bonds, the spread is higher by around 5 bp for green bonds while at the same time the maturity is 1-2 years longer. For each announcement, we show summary statistics of the matched conventional-green bond sample in Table C.3.

Table C.3: Matching Green to Conventional Bonds: Summary Statistics

Date	BA-Spread			Coupon		Spread		Maturity		Amount	
	#	Green	Conv.	Green	Conv.	Green	Conv.	Green	Conv.	Green	Conv.
08-11-2018	80	0.34	0.33	1.08	1.05	47.50	42.20	7.6	6.0	716	719
05-02-2020	89	0.33	0.32	1.16	1.10	45.97	41.63	6.7	5.1	713	698
27-02-2020	86	0.35	0.32	1.18	1.15	51.67	44.82	6.7	5.2	696	690
17-07-2020	86	0.44	0.38	1.22	1.22	77.49	72.10	6.5	4.9	693	689
21-09-2020	79	0.38	0.36	1.18	1.15	64.94	56.37	6.3	4.5	701	709

Notes: We denote the number of matches by #. Conv. denotes a *conventional* bond. Bond yield spreads over the Euribor/Swap are in basis points. Bid-ask spread and coupon relative to a face value of 100, maturity in years. Amount outstanding is in million EUR.

In the main text, we only display the average response across treatment dates, while Table C.4 gives details on single events. We observe significantly negative premia for green bonds up to one month after the treatment events. The strongest effect is visible for ECB president Christine Lagarde’s speech at February 27<sup>th</sup> 2020, which included the first explicit reference to the ECB’s collateral framework. Moreover, the speech delivered by Isabel Schnabel on July 17<sup>th</sup> 2020 stands out, since yields on green bonds significantly increased compared to their conventional counterparts in the days following the event. However, the tone regarding future ECB environmental policy is much more modest than in other speeches. There is also no explicit prospect of preferential treatment in this speech.<sup>24</sup>

Table C.4: Yield Reaction around ECB Policy Announcements

Date	Type	Yield Reaction	Standard Error
08-11-2018	Board Member Speech	-7.9***	1.78
05-02-2020	President Speech	-4.5**	0.89
27-02-2020	President Speech	-35.4***	7.19
17-07-2020	Board Member Speech	9.9***	1.8
21-09-2020	President Speech	0.6	1.2

Notes: We display the *average* yield over 20 days after minus *average* yield over 20 trading day before the policy announcement, relative to the matched control group (in basis points). Significance levels correspond to 10 % (\*), 1 % (\*\*) and 0.1 % (\*\*\*) of Welch’s t-test.

We also perform our analysis for six speeches that are unrelated to environmental policy in Table C.5. We do not find any significantly negative effects and conclude that the overall impact

<sup>24</sup>For example, Central Banks “*need to be mindful of their effects on market functioning*” and are required to exert effort towards environmental concerns only “*within their traditional mandates*”. Indeed, as our structural analysis in section 3 predicts, taking environmental concerns into account is not clearly motivated by the ECB mandate of price and financial stability.

of ECB environmental policy announcement is unlikely to be explained by a general negative trend in the greenium.

Table C.5: Yield Reaction around Non-Related ECB Policy Announcements

Date	Speech	Yield Reaction	Standard Error
01-10-2019	Mario Draghi (ECB)	2.64***	0.73
06-11-2019	Luis de Guindos (ECB)	1.70**	0.84
16-12-2019	Luis de Guindos (ECB)	4.25***	0.74
10-06-2020	Isabel Schnabel (ECB)	6.31***	2.64
27-08-2020	Philip R. Lane (ECB)	3.35**	0.95

Notes: We display the *average* yield over 20 days after minus *average* yield over 20 trading day before the policy announcement, relative to the matched control group (in basis points). Significance levels correspond to 10 % (\*), 1 % (\*\*) and 0.1 % (\*\*\*) of Welch's t-test.

## D The Pricing of Environmental Performance

Having established that green bond spreads behave systematically different from conventional bond spreads after ECB announcements related to the treatment of green bonds in its operations, this section explores whether market participants (independently) price environmental effort by issuers. To formally analyze the presence of an environmental effort factor, this section combines corporate bond data from *IHS Markit* with environmental performance data from *Refinitiv* database<sup>25</sup>. The environmental score is composed of three items (Resource Use, Emissions, Innovation), each ranging from 0 (worst) to 100 % (best). The data provider *Refinitiv* compiles the score annually by aggregating frequency and severity of environmental incidents associated with the firm. The algorithm used to compute the scores is proprietary, but is a standard benchmark in the green finance literature. To match ESG data with corporate bond data, we take the following steps:

- Match all company names from Markit iBoxx constituent lists to company names in our ESG dataset.<sup>26</sup> We construct a mapping from Markit firm ticker to Thomson Reuters firm ticker.
- Construct a dataset (2011-2019) of Markit bond market data based on matched Markit identifiers.<sup>27</sup> Supplement with data on environmental performance via the mapping to the ESG data.

<sup>25</sup>We obtain these data through *Thomson Reuters Eikon*.

<sup>26</sup>We match 148 out of 449 companies. Different string matching approaches did not alter the number of matches.

<sup>27</sup>In particular, we use coupon, maturity, bid(ask)-price, accrued interest, industry, rating and years to maturity.

- Exclude financial firms and compute the yield spreads with respect to the EURIBOR-Swap curve.

Our sample contains 2759 bond-year observations, issued by 60 different firms. Firms in our sample are large and they have multiple bonds outstanding at a given time. Descriptive statistics are summarized in in Table D.1.

Table D.1: Summary Statistics

	Mean	SD	p <sup>1</sup>	p <sup>25</sup>	p <sup>50</sup>	p <sup>75</sup>	p <sup>99</sup>
Coupon	3.56	1.89	0.13	1.88	3.64	4.88	8.50
BA-Spread	0.55	0.36	0.13	0.32	0.47	0.68	1.94
Spread	116	149	2	36	66	133	698
Rem. Life	6.91	9.10	1.15	3.19	5.24	7.79	58.57
E-Score	76.03	14.73	26.83	69.03	79.65	86.06	96.94
Emission	82.18	17.75	17.14	75.56	88.02	95	99.50
Resource Use	83.17	16.79	19.44	74.32	89.51	95.54	99.57
Sector	Consumer 17.29 %	Energy 30.99 %	Healthcare 3.66 %	Industrials 18.34 %	Materials 15.95 %	Technology 13.77 %	
Rating	AAA 0 %	AA 1.16 %	A 19.76 %	BBB 56.22 %	BB 12.14 %	B 0.72 %	

*Notes:* The table describes the dataset used for the regression in Table D.2. The coupon and spread are denoted in basis points. The BA-spread denotes bond prices per 100 EUR of face value. Remaining life is measured in years.

On the corporate bond sample, we run the regression

$$S_{i,t} = v_t + v_s + \beta_1 E_{j,t} + \beta_2 BidAskSpread_{i,t} + \beta_3 Rating_{j,t} + \beta_4 Years2Maturity_{i,t} + \epsilon_{i,t} ,$$

where  $S_{i,t}$  is the spread relative to EURIBOR/Swap of bond  $i$  issued by firm  $j$  in year  $t$ . Here  $v_t$  are time fixed effects and  $v_s$  are sector fixed effects. Bond spreads are measured in basis points, the bid-ask spread is expressed in terms of bond prices per 100 EUR of face value. The reference category for rating is AA. The results in Table D.2 show that after controlling for liquidity and credit risk proxies as well as sector dummies, there is no visible effect of environmental performance measures on bond spreads. Depending the specific score, the coefficient switches signs and is never significant.

Table D.2: Panel Results: Corporate Bonds

Coefficient	Environmental Pillar	Emission Score	Resource Use Score
Score	-0.144 (0.115)	-0.129 (0.113)	0.008 (0.01)
Bid-Ask-Spread	149.52 (20.29)***	149.38 (20.30)***	149.39 (20.24)***
Years to Maturity	-0.687 (0.358)*	-0.686 (0.360)***	-0.699 (0.360)***
A-rated	63.882 (10.79)***	64.32 (10.85)***	63.314 (10.91)***
BBB-rated	114.29 (11.55)***	114.22 (11.54)***	113.34 (11.61)***
BB-rated	250.37 (16.71)***	249.53 (16.63)***	250.32 (16.97)***
B-rated	681.67 (103.54)***	681.63 (103.63)***	681.89 (103.42)***
$R^2$	0.623	0.629	0.627

Notes: Significance levels correspond to 10 % (\*), 1 % (\*\*) and 0.1 % (\*\*\*).

There are few empirical results regarding the pricing of *environmental effort* on the corporate bond market, but these point in a similar direction as our findings: Zerbib (2019) finds evidence for only a small negative yield premium on green bonds compared to a comparable conventional bond using a relatively broad sample of US bonds. The premium that can be explained by investor preferences amounts to merely 2bp. Larcker and Watts (2020) find a green bond premium of zero for US municipal bonds. Their identification is appealing, since US municipalities regularly issue green and conventional bonds in tandem auctions at the same day. Our analysis comes to a similar conclusion using European bond-level data: corporate bond investors do not price environmental efforts of bond issuers per se. This observation will be guiding modelling choices regarding financial frictions faced by entrepreneurs in the structural model.