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Abstract

We study the preferential treatment of green bonds in the central bank collateral framework as an environmental policy instrument within a DSGE model with environmental and financial frictions. Green and conventional firms issue corporate bonds to banks that use them as collateral. The associated collateral premium induces firms to increase bond issuance, investment, leverage, and default risk. Collateral policy solves a trade-off between increasing collateral supply, adverse effects on firm risk-taking, and subsidizing green investment. Due to these adverse effects, optimal collateral policy is characterized by modest preferential treatment, thereby increasing the green bond share and, to a smaller extent, the green investment share, which reduces pollution. The limited response of green investment is directly related to higher risk-taking of green firms. Furthermore, we show that preferential treatment is an imperfect substitute of Pigouvian taxation on pollution: only if the optimal tax can not be implemented, optimal collateral policy features preferential treatment of green bonds.

Keywords: Green Investment, Collateral Framework, Environmental Policy

JEL Classification: E44, E58, E63, Q58

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1 Introduction

> *The ECB [...] stands ready to support innovation in the area of sustainable finance [...], exemplified by its decision to accept sustainability-linked bonds as collateral.*
> Strategy Review (European Central Bank, 2021a)

The European Central Bank (ECB) announced to take a more active role in environmental policy after concluding its strategy review. In addition to accepting sustainability-linked (*green*) bonds as collateral, several central banks contemplate to take one step further and treat them preferentially within their collateral frameworks, i.e., the conditions under which banks can pledge assets to obtain funding from the central bank.[1] The People's Bank of China (PBoC) started accepting green bonds as collateral on preferential terms already in 2018, which resulted in a substantial decline of green bond yields relative to conventional ones (Macaire and Naef, 2022). However, there is limited knowledge about the macroeconomic impact of a preferential collateral policy on green bond issuance, green investment, pollution, and potential adverse side effects on financial markets.

To study the positive and normative implications of preferential treatment, this paper extends the standard RBC-model by an environmental externality, green and conventional firms issuing corporate bonds subject to default risk, and a banking sector using these bonds as collateral. The extent to which corporate bonds can be used as collateral depends on central bank haircuts. Reducing haircuts on green bonds makes holding such bonds more attractive to banks and implies that they pay higher collateral premia on them. This in turn relaxes financing conditions for green firms, which increase bond issuance, investment and leverage in response: the equilibrium shares of green bonds and capital rise. We quantitatively assess these effects in a calibration to the euro area.

We uncover four main results. First, *maximal* preferential treatment, which applies a 100% haircut on conventional bonds and a 0% haircut on green bonds, increases the share of green bonds (capital) by almost 6% (3.7%), which reduces pollution. Second, in response to a preferential treatment green firms increase leverage, default risk, and dividend payouts. This risk-taking effect dampens the transmission of preferential treatment on green investment and increases resource losses from costly default. Because of these adverse effects, *optimal* collateral policy features a smaller degree of preferential treatment than the maximum case of only accepting green bonds. Third, Pigouvian taxes on pollution as alternative instrument do not induce risk-taking and the associated welfare gains exceed the gains from optimal collateral policy considerably. Fourth, preferential treatment is an *imperfect substitute* for Pigouvian taxation. The optimal degree of preferential treatment decreases, the closer Pigouvian taxes get to their optimal level. When Pigouvian taxation is optimal, green and conventional bonds are

[1] A similar policy was also proposed in Brunnermeier and Landau (2020).

treated *symmetrically*. In this case, however, the central bank optimally relaxes the collateral framework to address negative effects of environmental policy on collateral availability.

Our analysis is based on an extended RBC-model that connects collateral policy to financial market and environmental frictions. We assume that there are two types of intermediate good firms, green and conventional. Conventional firms generate a negative externality (pollution) during the production of intermediate goods, while green firms have access to a clean technology. Following Heutel (2012) and Golosov et al. (2014), final good firms combine green and conventional intermediate goods with labor. Pollution has a negative effect of final good firms' output, implying sub-optimally low investment into the green technology.

Collateral policy is linked to the real sector by the corporate bond market, where both intermediate good firms issue bonds to banks. Firms have an incentive to issue bonds, because their owners are assumed to be more impatient than households, who own banks. Moreover, firms are subject to idiosyncratic shocks to their productivity and default on their bonds if revenues from production fall short of current repayment obligations. Corporate bond issuance is determined by a trade-off between relative impatience and bankruptcy costs, similar to Gomes et al. (2016).[2] Banks collect deposits from households, invest into corporate bonds, and incur liquidity management costs. In the spirit of Piazzesi and Schneider (2021), these costs are decreasing in the amount of available corporate collateral reflecting that banks may use it to collateralize short-term borrowing. This introduces a willingness of banks to pay *collateral premia* on corporate bonds.[3]

The central bank sets haircuts on corporate bonds that determine the degree to which bonds can be used as collateral. While low haircuts increase collateral availability for banks, the central bank incurs costs from accepting risky bonds as collateral. The literature has associated these costs with risk management expenses and counterparty default risk that depend on the riskiness of collateral (Bindseil and Papadia, 2006; Hall and Reis, 2015). As in Choi et al. (2021), optimal collateral policy balances these two effects. Starting from this point, our paper studies the welfare gains of adding a second variable (the green haircut) to the central bank collateral framework.

The link between collateral policy and the real sector 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 favor of green bonds. In this case, banks pay higher collateral premia on green bonds, ceteris paribus, since holding them lowers liquidity management costs more effectively.

[2] Since our focus is on the collateral framework and thereby on firms that are sufficiently large to issue bonds and related marketable assets, we employ a financial friction that restricts *debt issuance* rather than overall *external financing* as in the canonical financial accelerator model of Bernanke et al. (1999). Moreover, our framework encompasses all marketable debt securities issued by non-financial firms, like syndicated bank loans and commercial paper.

[3] Collateral premia on corporate bonds are documented by Pelizzon et al. (2020) for the euro area, Mota (2020) for the US, and Fang et al. (2020) and Chen et al. (2021) for China.

Green firms respond to higher collateral premia on their bonds by increasing bond issuance and investment, while conventional firms reduce their bond and investment positions. However, since higher collateral premia make debt financing more attractive, green firms also increase leverage and risk-taking. Notably, the effect on the green investment share is *permanent*, i.e., central bank collateral policy is *not neutral* even in the long run.[4] Higher risk-taking reduces the expected return on green investment so 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. The endogeneity of risk-taking, which is key for the imperfect pass-through result, is consistent with the data.[5]

To quantify the optimal degree of preferential treatment, we calibrate the model to euro area data and conduct a number of policy experiments. First, we study a maximal preferential treatment policy, which makes conventional bonds non-eligible and accepts all green bonds without a haircut. This policy induces a green-conventional bond spread (also referred to as *greenium*) of 160 basis points in equilibrium, which translates into a change in the relative share of green bonds from 20% to 21.17%, while the share of green capital only increases from 20% to 20.74%. However, maximal preferential treatment reduces the collateral supply below its optimal level and distorts the risk choice of green firms. Therefore, we maximize the welfare objective over both haircut parameters. Optimal collateral policy still treats green bonds preferentially but increases the haircuts on conventional bonds to less than 100% to keep aggregate collateral supply approximately constant. In this case, the greenium amounts to 16 bp, the relative share of green bonds goes up to 20.11%, whereas the share of green capital increases to 20.07%.

While our numerical findings suggest that collateral frameworks can induce a shift towards green technologies, this shift is small and accompanied by adverse side effects. To put the effects of preferential treatment into perspective, we consider Pigouvian taxation of pollution, which is the natural policy instrument to address environmental frictions. Such a policy increases the share of green capital to 27.70% and substantially reduces the pollution externality *without* adverse effects on firm risk-taking. It should be noted that even without the adverse effects on firm risk-taking, Pigouvian taxes are an order of magnitude more powerful in addressing the environmental friction than *maximal* preferential treatment: the changes in bor-

[4] Asset purchase programs have an anti-cyclical component by design and, therefore, seem less well suited in an environmental policy context, which is concerned with long-run problems.

[5] Risk-taking, as reflected by firms' financing decision, has been reported in the empirical literature on unconventional monetary policy. Bekkum et al. (2018) observe a decrease in repayment performance on the mortgage backed securities market following an eligibility easing. Pelizzon et al. (2020) document positive leverage responses of eligible firms. Harpedanne de Belleville (2019) finds a sizable increase in investment by issuers of newly eligible bonds following a reduction of collateral requirements. Grosse-Rueschkamp et al. (2019) and Giambona et al. (2020) document a positive investment and leverage impact of firms eligible for quantitative easing. Kaldorf and Wicknig (2022) provide a structural analysis of collateral premia and corporate default risk.

rowing costs are unable to induce a sufficiently strong shift towards green technologies under any plausible calibration. If firms' financing choices are taken into account, the effectiveness of an optimal preferential collateral policy decreases by another order of magnitude.

These results should not be misinterpreted as a call for central bank inaction. The level of the Pigouvian tax that optimally addresses the environmental externality also reduces the collateral supply to an inefficiently low level. The central bank optimally addresses this by slightly decreasing haircuts in a symmetric way to restore the efficient level of aggregate collateral. In contrast, if public policy is restricted in its ability to set carbon taxes optimally, e.g., due to political economy frictions, the central bank can increase welfare by tilting the collateral framework towards green bonds. The extent of preferential treatment declines, the closer Pigouvian taxation gets to its optimal level: preferential treatment is a qualitatively and quantitatively imperfect substitute for taxation.

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, building on Heutel (2012). Punzi (2019) extends this setup by adding financial intermediation of loans to a credit-constrained corporate sector. Her paper explicitly considers differentiated capital requirements to relax financial frictions of green firms. Due to our focus on the collateral framework and marketable assets instead of bank loans, our model uses a financial friction related to leverage rather than external financing. Moreover, we endogenize firm risk-taking, while the extent of financial frictions is exogenous in Punzi (2019).

In a specific assessment of green QE, Ferrari and Nispi Landi (2020) find only a modestly positive impact on aggregate environmental performance. Similarly, Abiry et al. (2021) document a small impact of QE, in particular in comparison to a carbon tax, which is similar to our results on collateral policy. Hong et al. (2021) study sustainable investment mandates, which have a similar transmission mechanism, since they affect 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 wedges between green and conventional firms. Closest to our paper is the work of Papoutsi et al. (2021) who show how central banks can tilt their asset purchases towards green assets to address environmental frictions. However, they assume that central banks can 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. Similar to us, they show that in the presence of an optimal carbon tax, asset purchases play no role in addressing the environmental friction, consistently with the Tinbergen Principle in the public economics literature. On a more general level, all policies that change the relative demand for green and conventional bonds, such as green QE and preferential green capital requirements, will induce firm responses along several dimensions, that have not been studied extensively in the literature so far. However, in our view, a thorough analysis of these additional response margins is necessary to fully assess the effectiveness and efficiency of green policies.

It should be stressed, that we abstract from an analysis of transition risk, which arises if demand for conventional goods suddenly decreases due to ambitious environmental policy. Diluiso et al. (2021) and Carattini et al. (2021) argue that macroprudential policies can address this issue. Similar to these papers, we document an interaction between environmental policy and collateral policy and show how haircuts should be adjusted to account for these interactions.

Outline. The paper is structured as follows. We introduce our model in Section 2 and illustrate the pass-through of collateral policy to the real sector in Section 3. Section 4 presents our calibration, while we discuss our policy experiments in Section 5. Section 6 concludes.

2 Model

Time is discrete and indexed by $t = 1, 2, \ldots$. The model features a representative *household*, two types of *intermediate goods firms*, a perfectly competitive *wholesale firm*, aggregating both types of intermediate goods into a composite intermediate good, a competitive *final good producer*, financial intermediaries (*banks*), and a public sector consisting of a fiscal authority and the central bank. One type of intermediate goods producers (*conventional*) causes an externality when producing intermediate goods, to which we refer as *pollution*. The technology of the *green* firm does not cause the externality. Both types of intermediate goods are aggregated into a composite intermediate good by a perfectly competitive wholesale firm. A competitive final good producer uses the composite intermediate good and labor to produce the final consumption good, which it sells to the household. Banks raise deposits from the household to invest into corporate bonds and incur a liquidity management cost. Finally, the fiscal authority can levy a proportional pollution tax on the conventional firms' output, while the central bank sets the collateral framework and incurs a cost from collateral default.

2.1 Households and Banks

Households. The representative household derives utility from consumption c_t and disutility from supplying labor l_t at the wage w_t. To transfer resources across time, the household saves in deposits d_t. Deposits held from time $t-1$ to t earn the interest rate i_{t-1}. The household's discount factor is denoted by β, ω_l is the utility-weight on labor, and γ_c and γ_l are the inverses of the intertemporal elasticity of substitution and of the Frisch elasticity of labor supply, respectively. The maximization problem of the representative household is given by

$$
\begin{aligned}
V(d_t) = & \max_{c_t, l_t, d_{t+1}} \frac{c_t^{1-\gamma_c}}{1-\gamma_c} - \omega_l \cdot \frac{l_t^{1+\gamma_l}}{1+\gamma_l} + \beta \mathbb{E}_t \left[V(d_{t+1}) \right] , \\
& \text{s.t.} \quad c_t + d_{t+1} = w_t l_t + (1+i_{t-1}) d_t + \Pi_t ,
\end{aligned} \tag{1}
$$

where Π_t collects profits from banks and final goods producers and we omit the dependency of $V()$ on the aggregate state for simplicity. Solving (1) yields standard inter- and intratemporal optimality conditions

$$
c_t^{-\gamma_c} = \beta \mathbb{E}_t \left[(1+i_t) c_{t+1}^{-\gamma_c} \right] , \tag{2}
$$

$$
c_t^{-\gamma_c} w_t = \omega_l l_t^{\gamma_l} . \tag{3}
$$

Banks. There is a unit mass of perfectly competitive banks $i \in (0,1)$ that supply deposits to households and invest into corporate bonds. We assume that financial intermediation is subject to liquidity management costs, which can be represented by the function $\Omega(\overline{b}^i_{t+1})$, which satisfies $\Omega_{\overline{b},t} \equiv \partial \Omega / \partial \overline{b}^i_{t+1} < 0$, i.e., liquidity management costs depend negatively on the collateral value of bank i's corporate bond portfolio,

$$
\overline{b}^i_{t+1} = (1-\phi_c) q_{c,t} b^i_{c,t+1} + (1-\phi_g) q_{g,t} b^i_{g,t+1} .
$$

The collateral value of a bank's portfolio is given by the market value its bonds $q_{\tau,t} b^i_{\tau,t+1}$ weighted by one minus the respective central bank haircut parameter ϕ_τ.[6] The higher the haircut, the lower collateral value the bond has. Banks directly benefit from a relaxation in collateral policy, since this increases available collateral $\overline{b}_{t+1}$ ceteris paribus. The literature has motivated such liquidity management costs as arising from idiosyncratic liquidity shocks associated with deposit or credit line withdrawals (De Fiore et al., 2019 and Piazzesi and Schneider, 2021). The assumption $\Omega_{\overline{b},t} < 0$ then captures in reduced form the benefits of collateral to settle idiosyncratic liquidity shocks on interbank markets or by tapping central bank facilities.[7]

We follow Cúrdia and Woodford (2011) and assume that banks maximize profits, defined as equity value net of liquidity management costs in (4), subject to the solvency condition (5). Taken the behavior of other banks, intermediate firms, and central bank policy as given, the

[6] We restrict the analysis to time-invariant haircuts. While collateral frameworks are occasionally adjusted in practice, this usually happens in response to large shocks to the financial systems. These events are not of first order importance for our analysis of preferential treatment.

[7] Since neither the sources of liquidity demand, 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 Appendix A.1 for details on a micro-foundation.

maximization problem of bank i reads

$$\max_{d^i_{t+1}, b^i_{c,t+1}, b^i_{g,t+1}} \quad \Pi^i_t = d^i_{t+1} - q_{c,t} b^i_{c,t+1} - q_{g,t} b^i_{g,t+1} - \Omega(\overline{b}^i_{t+1}) \,, \tag{4}$$

$$\text{s.t.} \quad (1+i_t) d^i_{t+1} = \mathbb{E}_t \left[\mathcal{R}_{c,t+1}\right] b^i_{c,t+1} + \mathbb{E}_t \left[\mathcal{R}_{g,t+1}\right] b^i_{g,t+1} \,. \tag{5}$$

The bond payoff $\mathcal{R}_{\tau,t+1}$ depends on firm τ's bond issuance and capital choice via the default decision in period $t+1$ (see below). Taking first order conditions we obtain the bond price equation

$$q_{\tau,t} = \frac{\mathbb{E}_t \left[\mathcal{R}_{\tau,t+1}\right]}{(1+i_t)(1+(1-\phi_\tau)\Omega_{\overline{b},t})} \,. \tag{6}$$

Liquidity management costs introduce a willingness to pay a premium for eligible bonds, reflected by the term $(1-\phi_\tau)\Omega_{\overline{b},t}$, which we refer to as *collateral premium*.

2.2 Firms

Final Good Producer. A competitive firm produces the final good y_t using a Cobb-Douglas production function that combines an intermediate good z_t and labor l_t

$$y_t = (1-\mathcal{P}_t) A_t z_t^\theta l_t^{1-\theta} \,, \tag{7}$$

where θ is a technology parameter. Final good production is negatively affected by pollution $\mathcal{P}_t$ generated by the conventional firm (described below). The economy-wide TFP shock A_t evolves according to

$$\log(A_{t+1}) = \rho_A \log(A_t) + \sigma_A \varepsilon^A_{t+1} \,, \quad \varepsilon^A_{t+1} \sim N(0,1) \,,$$

Solving the maximization problem of the firm, we get standard first order conditions that equate the marginal product of the inputs to their market price

$$\begin{aligned} p_{z,t} &= (1-\mathcal{P}_t)\, \theta A_t z_t^{\theta-1} l_t^{1-\theta} \,, \\ w_t &= (1-\mathcal{P}_t)\, (1-\theta) A_t z_t^\theta l_t^\theta \,, \end{aligned}$$

where $p_{z,t}$ denotes the intermediate good price.

Wholesale Firm. The competitive wholesale firm bundles green and conventional intermediate goods into an input used by the final good firm using a Cobb-Douglas technology

$$z_t = z_{g,t}^{\nu} z_{c,t}^{1-\nu} \; , \tag{8}$$

where ν determines the relative share of green intermediate goods.[8] The prices of the intermediate good types τ are denoted by $p_{\tau,t}$. Solving the profit maximization problem yields

$$\nu p_{z,t} z_t = p_{g,t} z_{g,t} \; , \tag{9}$$

$$(1-\nu) p_{z,t} z_t = p_{c,t} z_{c,t} \; . \tag{10}$$

Intermediate Good Firms: Technology. There are two types of intermediate good firms producing a green or a conventional good z_τ. Within each type $\tau = \{c, g\}$, there is a unit mass of firms, indexed by j, that invest in physical capital $k_{j,\tau,t}$. The production technology of all firms is linear and subject to an idiosyncratic productivity shock $m_{j,\tau,t}$, which is i.i.d. across and within firm types

$$z_{j,\tau,t} = m_{j,\tau,t} k_{j,\tau,t} \; . \tag{11}$$

Following Bernanke et al. (1999), the idiosyncratic shock is log-normally distributed with $\mathbb{E}[m_{j,\tau,t}] = 1$. The log-normal distribution satisfies a monotone hazard rate property of the form $\partial(h(m_{j,\tau,t})m_{j,\tau,t})/\partial m_{j,\tau,t} > 0$, where $h(m_{j,\tau,t}) \equiv f(m_{j,\tau,t})/(1-F(m_{j,\tau,t}))$ denotes the hazard rate and $f(m_{j,\tau,t})$ and $F(m_{j,\tau,t})$ denote the pdf and cdf, respectively. Capital $k_{j,\tau,t}$ depreciates at rate δ, which is common to both production technologies. Sector-specific investment is denoted $i_{\tau,t}$. Since our model permits exact aggregation into representative firms, the law of motion for capital of type τ is given by

$$k_{\tau,t+1} = i_{\tau,t} + (1-\delta) k_{\tau,t} \; . \tag{12}$$

As common in environmental DSGE models (see Heutel, 2012), the aggregate production of conventional firms $z_{c,t}$ induces pollution $\mathcal{P}_t$, which satisfies $\partial \mathcal{P}_t / \partial z_{c,t} > 0$. Revenues are subject to a time-invariant, type-specific tax χ_τ. When χ_τ is negative, it can be interpreted as a subsidy and it will be set to zero in the baseline calibration.[9]

[8] In Appendix B.1 we conduct a robustness analysis using a CES-function and find only minor differences.

[9] It is not relevant in our setup, whether the intermediate or wholesale firms pay the tax. Attributing it to intermediate good producers, however, gives the cleanest comparison to collateral policy, as both instruments operate through the investment decision.

Intermediate Good Firms: Financial Side. As in Gomes et al. (2016), we assume that each firm j of each type τ is managed on behalf of a risk-averse and impatient representative firm owner who consumes dividends $\widetilde{c}_t = \int_j \Pi_{j,c,t} dj + \int_j \Pi_{j,g,t} dj$. The firm owner's period utility is given by $\frac{\widetilde{c}_t^{1-\gamma_c}}{1-\gamma_c}$, where the utility parameter is the same as the one of households. There is no agency friction between firm managers and owners. The representative firm owner discounts the future with a discount factor $\widetilde{\beta} < \beta$. This assumption ensures that firms borrow from banks in equilibrium. We impose the following timing structure:

- At the beginning of each period, firms enter with (type-specific) capital $k_{\tau,t}$ and bonds outstanding $b_{\tau,t}$.
- Each firm j draws an idiosyncratic productivity shock $m_{j,\tau,t}$, produces and either repays its maturing debt obligations or defaults (described below).
- Firms adjust capital $k_{j,\tau,t+1}$ and bonds outstanding $b_{j,\tau,t+1}$.
- Firms transfer their dividends $\Pi_{j,\tau,t}$ to the firm owner.

Firms finance their activities by issuing equity, modeled as negative dividends, or by issuing corporate bonds. Bonds mature stochastically each period with probability $0 < s \leq 1$ and pay one unit of the final good in $t+1$ in case of no default.[10] Firms mechanically default, if their repayment obligation exceeds revenues from production.[11] The default productivity threshold is given by $\overline{m}_{\tau,t}$ and is implicitly defined as the productivity level at which revenues $(1-\chi_\tau)p_{\tau,t}m_{\tau,t}k_{\tau,t}$ equal repayment obligations $sb_{\tau,t}$. In case of default, banks holding distressed bonds effectively replace the firm owner as shareholder: they seize the output *only in the default period*, restructure the firm, and resume to being creditors after the firm's debt has been restructured. With probability $1-s$, the bond does not mature, is unaffected by the restructuring process, and is rolled over at next period's market price $q_{\tau,t+1}$. While in practice restructuring takes several periods, we follow Gomes et al. (2016) and take a shortcut by assuming that capital owners can restructure their liabilities without delays.

Firms maximize the present value of dividends, discounted using the firm owner's stochastic discount factor $\widetilde{\Lambda}_{t,t+1} \equiv \widetilde{\beta}\left(\widetilde{c}_{t+1}/\widetilde{c}_t\right)^{-\gamma_c}$. We conjecture that all firms enter any period t with the same legacy debt stock and capital to express dividends as

$$\Pi_{j,\tau,t} = \mathbb{1}\{m_{j,\tau,t} > \overline{m}_{\tau,t}\}\Big((1-\chi_\tau)p_{\tau,t}m_{j,\tau,t}k_{\tau,t} - sb_{\tau,t}\Big) - k_{j,\tau,t+1} + (1-\delta)k_{\tau,t} \\ + q_{\tau,t}\left(b_{j,\tau,t+1} - (1-s)b_{\tau,t}\right) .$$

[10]Using long-term bonds allows to obtain realistic leverage ratios in the calibration, but is not required for the transmission of collateral policy. Moreover, bonds are cast in real terms. We consider nominal bonds in Appendix B.2.

[11]We implicitly assume that there is no transfer of resources from productive to unproductive firms.

Under the assumption of no delays in restructuring and i.i.d. productivity shocks, next period's productivity can be integrated out in the objective function and the problem reduces to a two-period consideration

$$\max_{k_{j,\tau,t+1},b_{j,\tau,t+1}} -k_{j,\tau,t+1}+q_{\tau,t}\Big(b_{j,\tau,t+1}-(1-s)b_{\tau,t}\Big)$$
$$+\mathbb{E}_t\Bigg[\widetilde{\Lambda}_{t,t+1}\Bigg((1-G(\overline{m}_{j,\tau,t+1}))(1-\chi_\tau)p_{\tau,t+1}k_{j,\tau,t+1}+(1-\delta)k_{j,\tau,t+1}$$
$$-s\Big(1-F(\overline{m}_{j,\tau,t+1})\Big)b_{j,\tau,t+1}+q_{\tau,t+1}\Big(b_{j,\tau,t+1}-(1-s)b_{\tau,t}\Big)\Bigg)\Bigg]\,,$$

subject to the default threshold $\overline{m}_{j,\tau,t+1}\equiv\frac{sb_{j,\tau,t+1}}{(1-\chi_\tau)p_{\tau,t+1}k_{j,\tau,t+1}}$, the bond pricing condition (6) and taken as given the continuation value of bonds $q_{\tau,t+1}$. Since dividends of all firms are transferred to the firm owner and firms can access capital and bond markets irrespective of current default, idiosyncratic productivity risk washes out in the aggregate: current productivity is not relevant for the investment and debt issuance decisions and all type τ firms make the same choices $k_{\tau,t+1}$ and $b_{\tau,t+1}$. This allows aggregation into a representative green and conventional firm, respectively.

Let the average productivity of a defaulting firm be denoted by $G(\overline{m}_{\tau,t})\equiv\int_0^{\overline{m}_{\tau,t}} mdF(m)$. In case of default, the bank pays restructuring costs φ and is entitled to the entire production, valued at price $p_{\tau,t}$, while the payoff in case of repayment is $b_{\tau,t}$.[12] In summary, the *per-unit* bond payoff entering the bond pricing condition of banks (6) is given by

$$\mathcal{R}_{\tau,t}=s\left(G(\overline{m}_{\tau,t})\frac{p_{\tau,t}(1-\chi_\tau)k_{\tau,t}}{sb_{\tau,t}}+1-F(\overline{m}_{\tau,t})\right)-F(\overline{m}_{\tau,t})\varphi+(1-s)q_{\tau,t}\,. \tag{13}$$

The first term reflects the payoff from the share s of maturing bonds: it consists of the production revenues banks seize in case of default (first term in parenthesis) and the repayment of the principal in case of no default (second term). The term $F(\overline{m}_{\tau,t})\varphi$ reflects default costs incurred by banks. The share of bonds that are rolled over is valued at the bond market price $q_{\tau,t}$.

Intermediate Good Firms: Bond Issuance and Investment. As in Gomes et al. (2016), the bond price depends only on the default threshold $q_{\tau,t}=q(\overline{m}_{\tau,t+1})$. Plugging investment (12) and banks' bond pricing condition (6) into the Bellman equation, the Euler conditions for bond

[12] Attributing restructuring costs to green and conventional firms yields similar mechanics.

issuance and capital read

$$
\begin{aligned}
q'(\overline{m}_{\tau,t+1})\frac{\mathbb{E}_t[\overline{m}_{\tau,t+1}]}{b_{\tau,t+1}}\Big(b_{\tau,t+1}-(1-s)b_{\tau,t}\Big)+q(\overline{m}_{\tau,t+1})& \\
=\mathbb{E}_t\left[\widetilde{\Lambda}_{t,t+1}\Big(s(1-F(\overline{m}_{\tau,t+1}))+(1-s)q(\overline{m}_{\tau,t+1})\Big)\right]&, \qquad (14)\\
1=-q'(\overline{m}_{\tau,t+1})\frac{\mathbb{E}_t[\overline{m}_{\tau,t+1}]}{k_{\tau,t+1}}\Big(b_{\tau,t+1}-(1-s)b_{\tau,t}\Big)& \\
+\mathbb{E}_t\left[\widetilde{\Lambda}_{t,t+1}\Big((1-\delta)+(1-\chi_\tau)p_{\tau,t+1}\big(1-G(\overline{m}_{\tau,t+1})\big)\Big)\right]&. \qquad (15)
\end{aligned}
$$

The analytical steps are relegated to Appendix A.2. Equation (14) is a standard optimality condition equating the marginal benefit of issuing more bonds (LHS) to the marginal costs (RHS). Each additional unit of bonds increases funds available in period t by $q(\overline{m}_{\tau,t+1})$ 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 $\overline{m}_{\tau,t+1}$, the term $\mathbb{E}_t[\overline{m}_{\tau,t+1}]/b_{\tau,t+1}$ captures the increase of default risk arising from the issuance of an additional bond. This dilutes the value of existing bond investment $b_{\tau,t+1}-(1-s)b_{\tau,t}$. The risk choice has also implications for firm consumption in $t+1$. Each unit of bonds involves repayment of s, conditional on not defaulting. In addition, bond issuance also increases the rollover burden in $t+1$, further reducing expected consumption.

The optimality condition for capital (15) requires that the cost of purchasing capital (equal to one, LHS) equals its payoff, the RHS, consisting of two parts. The first line affects consumption in period t and represents an increase of the bond price that is due to a decrease of the default probability. The part in the second line increases consumption in period $t+1$ and is composed of the value of capital after depreciation and the marginal value of production net of taxes.

2.3 Public Policy and Resource Constraint

The central bank sets the collateral framework (ϕ_c, ϕ_g) and incurs costs from collateral default Λ_t. These costs depend positively on the default risk of pledged collateral $\Lambda_{\overline{F},t}>0$, defined as the firms' probability of default, weighted by the repo size

$$
\overline{F}_t \equiv \sum_\tau (1-\phi_\tau)b_{\tau,t}q_{\tau,t}F_{\tau,t} \,.
$$

The weighting $(1-\phi_\tau)b_{\tau,t}q_{\tau,t}$ can be interpreted as the repo size collateralized by green and conventional bonds, respectively. By setting haircuts, the central bank has a direct effect on the costs. Making Λ_t dependent on default risk captures in reduced form a risk management consideration of accepting risky bonds as collateral. In Appendix A.3 we discuss a potential micro-foundation of the cost function, based on central bank solvency concerns (Hall and Reis, 2015). This is a frequently employed argument for why central banks are only willing to lend against sufficiently safe securities. For example, Bindseil and Papadia (2006) argue that central banks are not specialized credit risk management agencies and that higher default risk of accepted collateral makes monetary policy implementation more resource-intensive.

Together with the assumptions that liquidity management costs decrease in collateral supply, $\Omega_{\overline{b},t} < 0$, the assumption $\Lambda_{\overline{F},t} > 0$ introduces a collateral policy trade-off. To close the model, we assume that the fiscal authority rebates all tax revenues to green firms to balance its budget,

$$\chi_c p_{c,t} z_{c,t} + \chi_g p_{g,t} z_{g,t} = 0 \,. \tag{16}$$

This fiscal rule allows us to abstract from additional fiscal instruments that would otherwise be necessary to balance the government budget. The resource constraint is given by

$$y_t = c_t + \sum_{\tau} (c_{\tau,t} + i_{\tau,t}) + \Omega(\overline{b}_{t+1}) + \Lambda(\overline{F}_{t+1}) + \sum_{\tau} \varphi F(\overline{m}_{\tau,t}) b_{\tau,t} \,, \tag{17}$$

where the last three terms represent the resource losses due to the liquidity management costs, collateral default costs, and corporate defaults.

3 The Transmission of Preferential Treatment

Before numerically evaluating optimal policy in Section 4, we illustrate the pass-through of collateral policy and Pigouvian taxation in a simplified setting. The discussion will be organized around intermediate good firms' first order conditions and the equilibrium green capital ratio. For the ease of exposition, we consider the case of one-period bonds and full capital depreciation ($s = \delta = 1$). Since we do not focus on macroeconomic dynamics in this section, we do not endogenize output prices and the interest rate and also set firm owner's stochastic discount factor $\Lambda_{t,t+1} = \widetilde{\beta}$.

A Benchmark Without Default Risk. To isolate the role of financial frictions in the production sector, it is informative to relate our model to a framework without default risk and with collateral premia. Specifically, we consider the case where capital has to be fully debt-financed but where there are no idiosyncratic productivity shocks. In this case, both intermediate good firms will issue exactly as many bonds as necessary to finance their capital $q_{\tau,t} b_{\tau,t+1} = k_{\tau,t+1}$, taken as given bond prices. In the absence of default risk, the bond price $q_{\tau,t} = \frac{1}{(1+i_t)(1+(1-\phi_\tau)\Omega_{\overline{b}})}$ merely reflects the discounted value of consumption in $t+1$ and collateral benefits. The bond price is increasing in the collateral premium $\frac{\partial q_{\tau,t}}{\partial(1-\phi_\tau)\Omega_{\overline{b}}} > 0$, which in turn increases if the central bank lowers the haircut. Firms maximize the present value of dividends, which yields the following first order condition for capital

$$1 = \underbrace{(1-\chi_\tau)\mathbb{E}_t[p_{\tau,t+1}]q_{\tau,t}}_{\equiv \Gamma^{\text{no default}}_{\tau,t+1}} . \tag{18}$$

This condition states that the marginal cost of investment (LHS, equal to one) equals the marginal benefit of investment (RHS, return on capital $\Gamma^{\text{no default}}_{\tau,t+1}$). Given that the marginal cost of capital is constant, any increase of the return on capital will stimulate investment. A relaxation in collateral policy will then increase the return on capital proportionally to any increase of the bond price, which we refer to as *perfect pass-through*:

$$\frac{\partial \Gamma^{\text{no default}}_{\tau,t+1}}{\partial(1-\phi_\tau)\Omega_{\overline{b}}} = (1-\chi_\tau)\mathbb{E}_t[p_{\tau,t+1}]\frac{\partial q_{\tau,t}}{\partial(1-\phi_\tau)\Omega_{\overline{b}}} . \tag{19}$$

Combining the investment decision (18) for both firm types with the intermediate good demands (9) and (10) yields the green capital ratio

$$\frac{k_{g,t}}{k_{c,t}} = \frac{q_{g,t}}{q_{c,t}}\frac{\nu(1-\chi_g)}{(1-\nu)(1-\chi_c)} . \tag{20}$$

Equation (20) shows that in the no-default benchmark, a decrease in the relative borrowing costs of green firms increases the green capital ratio.

The Role of Default Risk. Now, consider the model with default risk. With one-period bonds, the default threshold is given by $\overline{m}_{\tau,t+1} = \frac{b_{\tau,t+1}}{(1-\chi_\tau)p_{\tau,t+1}k_{\tau,t+1}}$ and the first order conditions for bonds and capital simplify to

$$q'(\overline{m}_{\tau,t+1})\mathbb{E}_t[\overline{m}_{\tau,t+1}] + q(\overline{m}_{\tau,t+1}) = \widetilde{\beta}\mathbb{E}_t[1-F(\overline{m}_{\tau,t+1})] , \tag{21}$$

$$1 = \underbrace{(1-\chi_\tau)\mathbb{E}_t\left[p_{\tau,t+1}\left(\widetilde{\beta}\left(1-G(\overline{m}_{\tau,t+1})\right) - q'(\overline{m}_{\tau,t+1})\overline{m}^2_{\tau,t+1}\right)\right]}_{\equiv \Gamma_{\tau,t+1}} . \tag{22}$$

The return on capital in (22) contains, first, the future output produced by an additional unit of capital conditional on not defaulting, $\widetilde{\beta}\left(1-G(\overline{m}_{\tau,t+1})\right.$. Second, it contains a bond price appreciation term, $q'(\overline{m}_{\tau,t+1})\overline{m}^2_{\tau,t+1}$, reflecting the reduction in default risk from higher investment. Combining (21) and (22) and differentiating the return on capital with respect to the collateral premium, we obtain

$$
\begin{aligned}
\frac{\partial \Gamma_{\tau,t+1}}{\partial (1-\phi_\tau)\Omega_{\overline{b}}} = (1-\chi_\tau)\mathbb{E}_t \Bigg[p_{\tau,t+1} \Bigg\{ \Big(\frac{\partial q_{\tau,t}}{\partial (1-\phi_\tau)\Omega_{\overline{b}}} + q'(\overline{m}_{\tau,t+1}) \frac{\partial \overline{m}_{\tau,t+1}}{\partial (1-\phi_\tau)\Omega_{\overline{b}}} \Big) \overline{m}_{\tau,t+1} \\
+ q_{\tau,t} \frac{\partial \overline{m}_{\tau,t+1}}{\partial (1-\phi_\tau)\Omega_{\overline{b}}} - \widetilde{\beta} \big(1-F(\overline{m}_{\tau,t+1})\big) \frac{\partial \overline{m}_{\tau,t+1}}{\partial (1-\phi_\tau)\Omega_{\overline{b}}} \Bigg\} \Bigg] .
\end{aligned} \tag{23}
$$

As in the no-default case, the effect of collateral policy on the return on capital directly depends on the change in borrowing cost $\frac{\partial q_{\tau,t}}{\partial (1-\phi_\tau)\Omega_{\overline{b}}}$. Moreover, it also depends on the risk choice, which itself is endogenously determined. To characterize the risk choice, we exploit that banks' bond pricing condition is available in closed form. To simplify the exposition, assume that banks cannot seize output of defaulting firms (their revenues are wasted) and do not incur restructuring costs ($\varphi = 0$). The bond pricing condition and its derivative with respect to risk-taking can then be written as

$$
q(\overline{m}_{\tau,t+1}) = \mathbb{E}_t \frac{1-F(\overline{m}_{\tau,t+1})}{(1+i_t)(1+(1-\phi_\tau)\Omega_{\overline{b}})} \quad \text{and} \quad q'(\overline{m}_{\tau,t+1}) = \mathbb{E}_t \frac{-f(\overline{m}_{\tau,t+1})}{(1+i_t)(1+(1-\phi_\tau)\Omega_{\overline{b}})} .
$$

The effect of collateral policy on risk-taking can be illustrated by plugging the bond pricing condition into (21):

$$
(1+i_t) \left(\frac{1}{1+i_t} - (1+(1-\phi_\tau)\Omega_{\overline{b}})\widetilde{\beta} \right) = \mathbb{E}_t \left[\frac{f(\overline{m}_{\tau,t+1})}{1-F(\overline{m}_{\tau,t+1})} \overline{m}_{\tau,t+1} \right] . \tag{24}
$$

In the absence of collateral premia ($\phi_\tau = 1$), the risk choice is determined by equating relative impatience and marginal default costs. Holding the interest rate fixed, a reduction of the haircut ϕ_τ increases the LHS of (24). Due to the monotonicity assumption on the hazard rate, the RHS of (24) increases in $\overline{m}_{\tau,t+1}$. Hence, the effect of relaxing collateral policy on risk-taking is unambiguously positive. Intuitively, firms increase their risk-taking, because lower financing costs make investment *and* front-loading dividend payouts more attractive, holding expected default cost constant.

We can now re-consider the effect of haircuts on the return on capital (23). The term $q'(\overline{m}_{\tau,t+1}) \frac{\partial \overline{m}_{\tau,t+1}}{\partial (1-\phi_\tau)\Omega_{\overline{b}}} < 0$ is a negative risk-taking effect, which lowers the bond price and thereby makes investment less attractive in period t. The positive term $q_{\tau,t} \frac{\partial \overline{m}_{\tau,t+1}}{\partial (1-\phi_\tau)\Omega_{\overline{b}}}$ captures bond price appreciation from investment. Last, $\widetilde{\beta}\big(1-F(\overline{m}_{\tau,t+1})\big) \frac{\partial \overline{m}_{\tau,t+1}}{\partial (1-\phi_\tau)\Omega_{\overline{b}}}$ reflects the dividend reduction in $t+1$ due to higher default rates. Using the definitions of $q(\overline{m}_{\tau,t+1})$ and $q'(\overline{m}_{\tau,t+1})$, we can simplify (23) to

$$
\begin{aligned}
\frac{\partial \Gamma_{\tau,t+1}}{\partial (1-\phi_\tau)\Omega_{\overline{b}}} &= (1-\chi_\tau)\mathbb{E}_t\left[p_{\tau,t+1}\left\{\frac{\partial q_{\tau,t}}{\partial (1-\phi_\tau)\Omega_{\overline{b}}}\overline{m}_{\tau,t+1}\right.\right.\\
&\quad \left.\left.+\left(\underbrace{\frac{1-\frac{f(\overline{m}_{\tau,t+1})}{(1-F(\overline{m}_{\tau,t+1}))}\overline{m}_{\tau,t+1}}{(1+i_t)(1+(1-\phi_\tau)\Omega_{\overline{b}})}}_{=\widetilde{\beta}}(1-F(\overline{m}_{\tau,t+1}))-\widetilde{\beta}\big(1-F(\overline{m}_{\tau,t+1})\big)\right)\frac{\partial \overline{m}_{\tau,t+1}}{(1-\phi_\tau)\Omega_{\overline{b}}}\right\}\right]\\
&= (1-\chi_\tau)\mathbb{E}_t\left[p_{\tau,t+1}\overline{m}_{\tau,t+1}\right]\frac{\partial q_{\tau,t}}{\partial (1-\phi_\tau)\Omega_{\overline{b}}} < \frac{\partial \Gamma^{\text{no default}}_{\tau,t+1}}{\partial (1-\phi_\tau)\Omega_{\overline{b}}}\,.
\end{aligned}
$$

Hence, relaxing collateral policy has a positive but unambiguously smaller effect on investment than in the no-default case. In (partial) equilibrium, the green capital ratio in the presence of financial frictions can be written

$$
\frac{k_{g,t}}{k_{c,t}} = \frac{\mathbb{E}_t\left[\widetilde{\beta}\big(1-G(\overline{m}_{g,t+1})\big)-q'(\overline{m}_{g,t+1})\overline{m}^2_{g,t+1}\right]}{\mathbb{E}_t\left[\widetilde{\beta}\big(1-G(\overline{m}_{c,t+1})\big)-q'(\overline{m}_{c,t+1})\overline{m}^2_{c,t+1}\right]}\frac{\nu(1-\chi_g)}{(1-\nu)(1-\chi_c)}\,. \tag{25}
$$

Absent preferential treatment, the risk choice and bond prices are identical across firm types and the terms related to financial frictions in the return on investment cancel. Then, as in the no-default case, the relative size of both sectors would be directly determined by the technology parameter ν and the environmental policy regime. Setting $\chi_c > 0$ and $\chi_g < 0$ directly increases the green capital ratio. Note that this policy also operates through the return on capital, which increases (decreases) in the subsidy (tax) from (18). However, in sharp contrast to haircut policies, the tax rate χ_τ does not affect risk-taking, as demonstrated in (24). The preferential treatment of green bonds in the collateral framework also increases the green capital ratio, but the pass-through of this policy is impaired. We quantify relevance of this impairment in the next section.

Last, note that two partial effects shape the effect of preferential treatment and the extent to which financial frictions dampen it: (i) the response of relative borrowing costs between sectors to preferential treatment and (ii) the elasticities of leverage and capital to bond price changes. In Section 4.2, we relate the model-implied reactions in these dimensions to the data. Separating between-sector effects on borrowing costs from sector-specific effects of borrowing conditions on real outcomes is relevant from an empirical point of view: as preferential policies are not enacted yet, this decomposition allows to assess the model predictions' plausibility.

4 Quantitative Analysis

In this section, we provide a calibration of the model to euro area data. All data sources are summarized in Appendix D. We then show the model's fit regarding (untargeted) macroeconomic dynamics and demonstrate the model's ability to replicate the effect of preferential treatment on borrowing costs between sectors and the response of financial market and real sector variables to collateral policy.

4.1 Calibration

Each period corresponds to one quarter. We assume log-utility over consumption, fix the inverse Frisch elasticity at 1, and set the household discount factor β to 0.99. The Cobb-Douglas coefficient in the final good production technology is set to $\theta = 1/3$ to get a labor share of $2/3$, and we choose the weight ω_l in the household utility function to be consistent with a steady state labor supply of $1/3$. The TFP shock parameters are conventional values in the RBC literature. The depreciation rate is set to $\delta = 0.017$ to target the capital to GDP ratio.

Parameters regarding pollution and the green technology share are important drivers of environmental DSGE models. 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 ν.[13] In spirit of Heutel (2012) and Golosov et al. (2014), we assume that pollution costs are expressed as

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

which, through final good production (7), 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 γ_P governs the pass-through from pollution to production losses. We inform the parameter γ_P 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 10% has also been reported in the fourth National Climate Assessment in the US (Reidmiller et al., 2018). Since economic activity in this dimension can be assumed to be similar in the US and the euro area, we adopt the same value.

[13] Renewable energy statistics for the EU are accessible here. See also the guide by Eurostat (2020).

The next group of parameters is associated with intermediate good firms. We assume that both firm types are subject to the same financial friction. This assumption is supported by the findings of Larcker and Watts (2020) and Flammer (2021), who find no effect of environmental performance on spreads in the US fixed income market. Average maturity of corporate bonds is set to five years ($s = 0.05$) and corresponds to average maturity in the *Markit iBoxx* corporate bond index between 2010 and 2019. Following Gomes et al. (2016), restructuring costs φ are set such that they are consistent with a recovery rate of 30%, defined as realized payoff in default over the promised payoff. The idiosyncratic productivity shock is log-normally distributed with variance ς_M and mean $-\varsigma_M/2$ to ensure that it satisfies $\mathbb{E}[m_{\tau,t}] = 1$. This leaves us with two free parameters, the discount factor $\widetilde{\beta}$ of firm owners and the idiosyncratic productivity variance ς_M. They are set to match time-series means of spreads and the corporate debt-GDP ratio. The model-implied bond spread is defined as

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

For the data moment on spreads, we use the *IHS Markit* data from 2010 until 2019. We compute the median bond spread over the entire corporate bond sample and average over time, which yields a value of around 100bp. The data moment on corporate debt is the non-financial firm debt to GDP ratio taken from the ECB.

The final group of parameters is related to banks and collateral policy. We impose symmetric collateral treatment and set $\phi_{sym} \equiv \phi_c = \phi_g = 0.26$, which corresponds to the current haircut on BBB-rated corporate bonds with five to seven years maturity. Liquidity management costs are specified as

$$\Omega\left(\overline{b}^i_{t+1}\right) = \max\left\{l_0 - 2l_1\left(\overline{b}^i_{t+1}\right)^{0.5}, 0\right\} \,. \tag{26}$$

Their concave shape captures that the marginal cost reduction of collateral is decreasing (in absolute terms), e.g., due to the re-use of existing collateral. The intercept parameter l_0 will be set sufficiently high to ensure that $\Omega(\overline{b}^i_{t+1})$ is positive for all considered collateral policy specifications.[14] Plugging in $\overline{b}^i_{t+1} = 0$ can be interpreted as the cost level of an entirely uncollateralized banking system.

The slope of the liquidity management costs l_1 governs the cost reduction per unit of collateral. We calibrate it to $l_1 = 0.0085$, matching the eligibility premium reported by the empirical literature: using the ECB list of collateral eligible for main refinancing operations, Pelizzon et al. (2020) identify an eligibility premium of -11bp. The model implied eligibility premium is given by the yield differential of the traded bond and a synthetic bond that is not eligible in

[14] We verify that l_0 does not visibly affect our results.

Table 1: Baseline Calibration

Parameter	**Value**	**Source/Target**
Households		
CRRA-coefficient γ_c	1	Log-utility
Household discount factor β	0.99	Annual riskless rate 4%
Labor disutility convexity γ_l	1	Frisch elasticity = 1
Labor disutility weight ω_l	6.68	Labor supply = 1/3
Firms		
Cobb-Douglas coefficient θ	1/3	Labor share = 2/3
Green goods share ν	0.20	Renewable share in Europe 2018
Externality Parameter γ_P	1.5e-2	Pollution damage/GDP = 0.1
Banks		
Bond maturity parameter s	0.05	*IHS Markit*
Restructuring costs φ	0.50	Recovery rate = 30%
Collateral default cost parameter η_1	0.0463	Ex-post optimality of $\phi_{sym} = 0.26$
Liquidity management intercept l_0	0.05	Ensures positive costs
Liquidity management slope l_1	0.0085	Eligibility premium = -11bp
Conventional and Green Firms		
Depreciation rate δ	0.067/4	Capital/GDP = 2.1
Discount factor $\widetilde{\beta}$	0.9835	Debt/GDP = 0.8
Standard deviation idiosyncratic risk ς_M	0.175	Bond spread = 100bp
Central Bank		
Haircut parameter ϕ_{sym}	0.26	ECB collateral framework
Shocks		
Persistence TFP shock ρ_A	0.95	Standard
Variance TFP shock σ_A	0.005	Standard

period t, but becomes eligible in $t+1$, corresponding to the identification strategy of Pelizzon et al. (2020). The advantage of this procedure is that the eligibility premium can be backed out from bond prices *in deterministic steady state*. The eligibility premium is available in closed form and given by

$$\widetilde{x}_{\tau,t} \equiv (1 + s/q_{\tau,t} - s)^4 - (1 + s/(q_{\tau,t}(1 + (1-\phi_\tau)\Omega_{\overline{b},t})) - s)^4 \,.$$

In the spirit of Bindseil and Papadia (2006), the costs of accepting risky collateral follow

$$\Lambda(\overline{F}_t) = 2\eta_1 \cdot (\overline{F}_t)^{0.5} \,.$$

Table 2: Model Fit – Second Moments

Moment	Model	Data	Source
Volatilities			
Bond Spread Vol. $\sigma(x)$	30 bp	50-100 bp	Gilchrist and Zakrajšek (2012)
Excess Vol. Consumption $\sigma(c)/\sigma(y)$	0.59	0.70	Euro area data
Excess Vol. Investment $\sigma(i)/\sigma(y)$	6.50	3.80	Euro area data
Persistence			
GDP $corr(y_t, y_{t-1})$	0.70	0.90	Euro area data
Consumption $corr(c_t, c_{t-1})$	0.87	0.80	Euro area data
Investment $corr(i_t, i_{t-1})$	0.60	0.80	Euro area data
Correlations with GDP			
Consumption $corr(y, c)$	0.86	0.60	Euro area data
Investment $corr(y, i)$	0.90	0.70	Euro area data
Debt $corr(y, b)$	0.70	0.65	Jungherr and Schott (2022)
Leverage $corr(y, lev)$	-0.77	-0.30	Kuehn and Schmid (2014)
Default risk $corr(y, F)$	-0.77	-0.55	Kuehn and Schmid (2014)
Pollution $corr(y, \mathcal{P})$	0.31	0.30	Doda (2014)

Notes: We calculate theoretical moments after solving the model under the productivity shock. We compare the model moments to Hodrick-Prescott-filtered data of the euro area or to moments from the literature.

The concave specification reflects that there is a fixed cost component to set up a proper risk management infrastructure as well as a marginal cost component from adding additional risk to the central bank's collateral portfolio, for example through more frequent collateral default. The parameter η_1 governs the level of collateral default costs and is set so that the empirical haircut value $\phi_{sym} = 0.26$ is optimal according to an utilitarian welfare criterion. Put differently, we assume that the status-quo ECB collateral policy is optimal under the restriction of symmetric collateral policy and parameterize the cost function accordingly. Finally, we define the *greenium* as the spread of conventional over green bonds with corresponding maturity

$$\widehat{x}_t = x_{g,t} - x_{c,t} \ .$$

Note that the greenium is zero in our baseline calibration due to the assumption of symmetric financial frictions and symmetric collateral treatment. The parameterization is summarized in Table 1.

Macroeconomic Dynamics. In Table 2, we compare the model-implied second moments with the data. Notably, they are broadly consistent with each other, even though our model only uses one exogenous shock and does not feature frictions related to firm investment, labor markets, and the relationship between households and banks. The time series volatility of bond spreads is slightly smaller than the value reported by Gilchrist and Zakrajšek (2012) for US data, since bond prices in our model are priced using a log-utility pricing kernel and only contain default risk compensation and the collateral premium.

The excess volatilities of consumption and investment are broadly consistent with euro area data. The elevated investment volatility and its low autocorrelation can at least partly be attributed to the absence of investment adjustment costs. The model is also able to capture the cyclical properties of key financial market variables, debt b, leverage at market values $qb/(pk)$, and default risk F. In addition, we also match the cyclicality of emissions, which has been estimated by Doda (2014) for a large sample of countries.

4.2 Real Effects of Preferential Treatment

Before using the calibrated model to study optimal preferential treatment, we compare the model-implied impact of preferential treatment to results from the empirical literature, which corroborates the external validity of our quantitative analysis. Guided by the simplified setting in Section 3, we first discuss the effect of preferential treatment on relative borrowing costs of green and conventional firms. In a second step, we then consider the effect of changes in borrowing costs on bond issuance and investment.

Preferential Treatment and Relative Borrowing Costs. To examine the effect of preferential central bank policy on (relative) bond prices, we exploit the yield reaction of green and conventional bonds around ECB announcements regarding environmental policy.[15] We identify four relevant speeches by ECB board members between 2018 and 2020, which explicitly mention environmental concerns for the conduct of central bank policy. Using data from *IHS Markit* and *Thomson Reuters Datastream*, we generate a panel of green-conventional bond pairs, obtained by a nearest-neighbor matching. We then compute the average yield difference between green bonds and their respective conventional counterparts for a 20 trading day window around each announcement. 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 4.8 bp on average over a 20 trading day window. 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 investors are willing to pay premia on green bonds already if there is the prospect of preferential treatment.

Since the ECB so far did not implement preferential treatment, these announcements can be mapped into our model by interpreting them as a news shock (see Beaudry and Portier, 2004 and Barsky and Sims, 2011). Specifically, we assume that preferential treatment will

[15] See Appendix C for details on the announcements and the data.

Table 3: Greenium Reaction – Announcement Effects

Data	**Model: Horizon**			
	2 years	3 years	4 years	5 years
-4.8 bp	-8.8 bp	-6.8 bp	-5.3 bp	-4.1 bp

Notes: The data value results from the analysis of announcement effects. Model-implied values obtain from introducing news shocks (27).

be implemented with certainty but at an unknown point in the future. We enrich the baseline calibration by a news shock to the green collateral parameter ϕ_g for various time horizons,

$$\log(\phi_{g,t}) = (1-\rho_\phi)\log(\phi_{sym}) + \rho_\phi \log(\phi_{g,t-1}) + \sigma_\phi \varepsilon^\phi_{t-h} \quad \varepsilon^\phi_{t-h} \sim N(0,1)\ , \tag{27}$$

where ϕ_{sym} is the green collateral parameter corresponding to the baseline calibration and h denotes the announcement horizon. We choose a high value of $\rho_\phi = 0.95$ for the haircut persistence, since changes to the collateral framework only occur infrequently. The shock size σ_ϕ is set such that $\phi_g = 0.045$ in two, three, four, or five years. The haircut value of 4.5% corresponds to the treatment of AAA-rated securities in the ECB collateral framework. This haircut appears to be a reasonable value for a strong preferential policy and opens a considerable haircut gap. Moreover, the considered horizons appear plausible, given that the ECB strategy review itself took two years and that the actual implementation of preferential treatment takes some additional time. The announcement effect on the greenium is shown in Table 3 and lies between -8.8 bp and -4.1 bp. Naturally, the effect peters out as the announcement horizon increases. The model-implied yield response closely resembles the data value at the four-year horizon.

Relative Borrowing Costs and their Real Effects. In the second step, we consider the firm level effect of a change in borrowing cost induced by central bank policy. We build on literature studying firm responses following QE-programs and collateral framework changes. From the point of view of firms (the collateral supply side), the effects of QE and collateral eligibility are identical, since in both cases banks increase demand for their bonds for reasons unrelated to firm fundamentals. Specifically, we compare estimate from the literature to the effects of a haircut decrease from $\phi_{sym} = 1$ (no eligibility) to $\phi_{sym} = 0.26$ (our baseline value). We assume that the collateral policy relaxation is *unanticipated*, comes into effect *immediately*, and is *permanent*. We focus on the reaction of bond yields, capital, and leverage, since our discussion of the imperfect pass-through of preferential treatment in Section 3 is centered around these variables .

Since the eligibility premium as defined in Pelizzon et al. (2020) is a calibration target, we instead examine the yield spread between eligible and non-eligible bonds. Fang et al. (2020)

study the impact of an easing of collateral eligibility requirements by the PBoC and identify a yield reaction on treated bonds of 42-62 bp (their Table 5). Using a similar approach, Chen et al. (2021) find a yield reaction of 39-85 bp (their Tables 5 and 8).

Regarding the financing of firms, Grosse-Rueschkamp et al. (2019) show that the introduction of the Corporate Sector Purchase Program (CSPP) triggered a positive response of total debt to assets for eligible firms relative to non-eligible firms prior to CSPP. The magnitude of the effect is estimated between 1.1 pp and 2.0 pp, depending on the econometric specification (see their Table 2). Pelizzon et al. (2020) report an increase of total debt/total assets between 2.5 pp and 10.8 pp (see their Table 10). Giambona et al. (2020) consider the impact of QE and find increases in total debt/total assets of around 1.8pp (see their Table 15).

On the same sample, they report an increase in investment between 4.9 pp and 6.0 pp for QE-eligible firms when controlling for firm characteristics (see their Table 3). Harpedanne de Belleville (2019), Table 4.1, finds a 5.4 pp increase in investment after the introduction of the Additional Credit Claims program using French data, which contains a large amount of small firms, which also contains firms without bond market access. Grosse-Rueschkamp et al. (2019) on the other hand only document a mild effect of 1pp on asset growth (their Table 5).

Table 4: Firm Reaction: Model vs. Data

	Δ Yield	**Δ Capital**	**Δ Leverage**
Model	58 bp	2.1 pp	1.4 pp
Data	39 - 85 bp	1.0 - 6.0 pp	1.1 - 10.8 pp

Notes: In the first line, we compare our baseline to an economy with 100% haircut. The second line displays the range of estimated effects taken from the empirical literature.

Table 4 displays our results. Consistent with the empirical literature, we observe a strong yield response to eligibility of around 58 bp. The capital response comfortably falls into the range of empirical estimates, while the model-implied leverage response is at the lower bound of the firm reaction observed in the data. The relatively modest leverage response will imply that the role of the adverse effects of preferential treatment on firm risk-taking are quantified in a conservative manner.

5 Policy Analysis

In this section, we conduct policy experiments regarding the collateral framework and its interactions with direct Pigouvian taxation of pollution. Throughout the analysis, we employ an utilitarian welfare criterion based on household's (unconditional) expected utility (1) and follow Schmitt-Grohé and Uribe (2007) by approximating it, together with the policy functions, up to second order. Given the log-utility assumption on consumption, the consumption equivalent (CE) welfare gain follows as

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

where V^{base} and V^{policy} are obtained from evaluating (1) under the baseline and alternative policies, respectively.[16]

5.1 Optimal Collateral Policy With Preferential Treatment

Since intermediate good firms are at the heart of the transmission mechanism of both policies, we begin by showing the model-implied means of financial market variables for different green haircuts in Figure 1. The green and red line denote the green and conventional firms, respectively. The upper panels show that green collateral premia strongly increase, the smaller the green collateral haircut ϕ_g, while at the same time the green bond spread declines, relative to the baseline calibration (solid vertical line).

[16] We also explore welfare gains conditionally on being at the deterministic steady state of the baseline calibration and taking into account the transition period to the new steady state. Results are virtually unchanged.

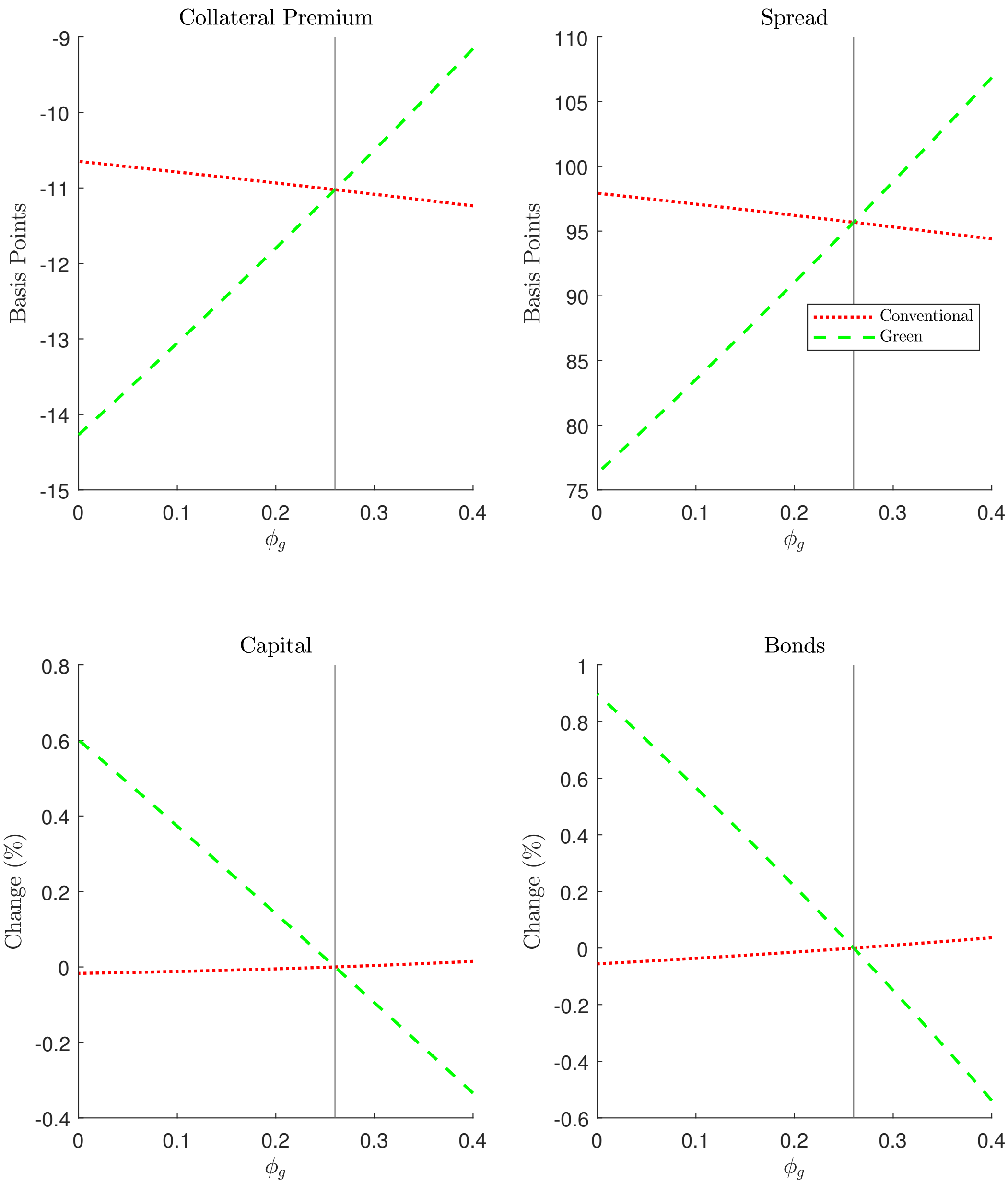

Figure 1: Firm Response to Preferential Treatment

Notes: We display long-run means for different green haircuts ϕ_g. The collateral premium and spreads are expressed in basis points, leverage and default rates in percentage points. Bonds outstanding and capital are shown relative to the baseline of $\phi_{sym} = 0.26$ (vertical line).

The lower financing costs of green firms increase the green capital holdings. For every haircut, the increase in investment falls short of the increase in bond issuance (lower panels), consistent with an increase in leverage: the pass-through of collateral policy is imperfect as outlined in Section 3. For all variables, the reaction of conventional firms mirrors the response of their green counterparts, although to a smaller extent. This is an equilibrium effect operating through the perfect substitutability of green and conventional bonds as collateral: the conventional collateral premium $(1-\phi_c)\Omega_{\overline{b},t}$ depends on haircuts and collateral supply. If $\overline{b}_t$ increases

Table 5: Time Series Means for Different Policies

Moment	**Baseline**	**Max Pref**	**Opt Coll**	**Only Tax**	**Glob Opt**
Tax Parameter χ_c	0	0	0	9.6%	9.6%
Haircut ϕ_g	26%	0%	11%	26%	21%
Haircut ϕ_c	26%	100%	29%	26%	21%
Welfare Change (CE)	0%	-0.6462%	0.0064%	+0.6640%	+0.6646%
Conv. Leverage	42.1%	41.4%	42.0%	42.1%	42.1%
Green Leverage	42.1%	42.5%	42.2%	42.1%	42.1%
Conv. Bond Spread	96bp	162bp	99bp	96bp	94bp
Green Bond Spread	96bp	2bp	83bp	96bp	94bp
Conv. Coll. Premium	-11bp	0bp	-11bp	-11bp	-11bp
Green Coll. Premium	-11bp	-27bp	-13bp	-11bp	-11bp
GDP	0.8494				
Change from Baseline	-	+0.05%	+0.02%	+0.58%	+0.61%
Restructuring Cost/GDP	2.30%				
Change from Baseline	-	-20.18%	+0.19%	-0.13%	+1.37%
Coll. Default Cost/GDP	1.65%				
Change from Baseline	-	-29.75%	+0.74%	-0.36%	+3.76%
Liq. Man. Cost/GDP	2.91%				
Change from Baseline	-	+46.91%	-0.47%	-0.86%	-4.37%
Pollution Cost/GDP	9.74%				
Change from Baseline	-	-1.64%	-0.06%	-8.66%	-8.59%
Green Bond Share	20%	21.17%	20.11%	27.68%	27.68%
Green Capital Share	20%	20.74%	20.07%	27.68%	27.68%

Notes: Maximal preferential treatment (*Max Pref*) only allows green bonds as collateral ($\phi_g = 0, \phi_c = 1$). The optimal collateral policy (*Opt Coll*) is derived from maximizing CE over a grid of haircuts. For the optimal tax (*Only Tax*), we hold haircuts fixed and vary the tax rate. The global optimum (*Glob Opt*) is obtained by maximizing over taxes and haircuts.

due to preferential treatment, this has a negative effect on the conventional collateral premium.

Our first finding considers the welfare and pollution impact of *maximal preferential treatment* in the second column of Table 5. We set $\phi_g = 0$ and $\phi_c = 1$ to provide an upper bound for the central bank's ability to induce investment into green technologies. The collateral premium on conventional bonds is zero in this case. This policy induces an increase in the green bond share to 21.17%, while green investment rises to 20.74%, translating into an 6% (3.7%) increase relative to the symmetric baseline (first column), respectively.

Around 40% of the effect on the corporate (green) bond market does not carry over to the investment decision due to the financial friction in the production sector. The converse holds for conventional firms, who reduce their bond issuance and capital holdings. This in turn lowers pollution. At the same time, setting $\phi_c = 1$ implies a strong contraction of collateral, leading to a substantial increase in liquidity management costs. Given the reduction in conventional bond issuance, we observe a decrease in the cost from debt restructuring and collateral default. Since optimal collateral policy trades off pollution with resources losses from corporate default and liquidity management costs, this combination of aggregate default rates and collateral supply is sub-optimal and substantially decreases welfare relative to the baseline collateral framework. Therefore, we maximize welfare over the collateral framework (ϕ_c, ϕ_g), to which we refer as the *optimal collateral policy*, and report results in third column of Table 5.

The optimal haircut levels of $\phi_g = 0.11$ and $\phi_c = 0.29$ imply a preferential treatment of green bonds. Subtracting the green bond spread of 83 bp from the conventional one of 99 bp gives a greenium of 16 bp, which is considerably smaller than under maximal preferential treatment. Consequently, the increase in the green bond (0.11 pp) and green capital (0.07 pp) shares is smaller as well. On the one hand, this policy avoids a sharp drop in available collateral. On the other hand, it reduces pollution less effectively. In Appendix B.1, we also show that nominal rigidities are not driving these results.

5.2 Interaction with Direct Taxation

While our analysis reveals that the central bank can affect the relative size of green and conventional firms and thereby reduce the pollution externality, this effect is relatively small and induces non-negligible side-effects. In this section, we benchmark these results against direct Pigouvian taxation of pollution externalities. Section 3 indicated that its effect on capital shares is more direct than the one of collateral policy. The exercise serves a dual purpose: first, we can put the effectiveness of preferential collateral treatment into perspective relative to Pigouvian taxation. Second, this allows us to examine a mix of direct taxation and collateral policies. By assuming a balanced budget in (16), 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 5 corresponds to optimal Pigouvian taxation, holding the collateral framework at its baseline value. The optimal tax on conventional production is at 9.6%, which implies a subsidy of around 40% on green intermediate goods, since taxes are rebated to conventional firms proportional to their relative sizes, as determined by the parameter ν in the wholesale good production function (8). The green capital share rises by 7.7 pp, which strongly tilts production towards green inputs and reduces the pollution externality. The welfare improvement of optimal Pigouvian taxation exceeds the improvement from optimal preferential treatment by two orders of magnitude. At the same time, there are no adverse effects on firm risk-taking, since the first order condition for leverage (14) is not affected by a tax on production. This suggests that fiscal instruments dominate preferential treatment in addressing environmental frictions.

However, this should not be misinterpreted as a call for central bank inaction, since Pigouvian taxation has also a collateral policy impact as reported in the fourth column of the third panel

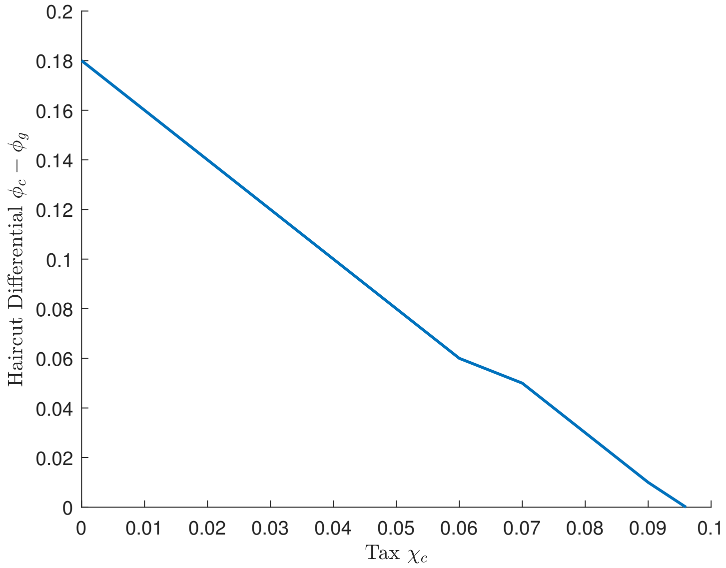

Figure 2: Optimal Collateral Policy Under Sub-Optimal Taxation

Notes: For different levels of the Pigouvian tax, we maximize CE over a grid of haircuts and display the result as the haircut differential.

in Table 5. We observe a simultaneous decline of liquidity management expenses and costs associated to default relative to GDP, respectively. The former results from a slight increase in available collateral driven by green firm bond issuance and the latter is a result of a drop in the bond issuance of conventional firms that lowers the size of costs from default. Both changes lower resources wasted but also shift the economy away from a configuration of the collateral trade-off for which the baseline haircuts are optimal. Relative to the global optimum, when collateral policy and taxes are set jointly, reported in the last column of Table 5, the collateral supply is too small at the old collateral framework driven by the reduction in conventional bond issuance. As a result, the collateral framework becomes more lenient. Notably, this relaxation is symmetric. This incentivizes all firms to increase their bond issuance, implying a slight increase of default cost while liquidity management cost decline substantially.[17] The welfare gains of adjusting collateral frameworks to mitigate negative effects on collateral availability are positive, but of small size compared to the welfare gains of optimal taxation.

The symmetry result hinges on the assumption that optimal Pigouvian taxes are available, which is arguably not an empirically plausible case. In Figure 2, we compute the optimal degree of preferential treatment, represented by the haircut differential, for different levels of the Pigouvian tax. At $\chi_c = 0$, the haircut gap is 18%, corresponding to the third column of Table 5, i.e., optimal collateral policy in the absence of taxation. At the globally optimal tax

[17]This is similar to Carattini et al. (2021), who show that macroprudential policy can alleviate adverse effects of carbon taxation. In their model, adverse effects take the form of asset stranding, while in our case adverse effects are linked to collateral availability, if conventional firms shrink their balance sheet size. Notably, optimal macroprudential policy is also symmetric in their model.

of $\chi_c = 0.096$, the gap is zero as in column five. While we are not explicit about why the Pigouvian might be too low, our model implies that the central bank can improve on sub-optimal taxation. However, the optimal degree of preferential treatment decreases, the closer environmental policy gets to implementing the optimal Pigouvian tax.[18]

6 Conclusion

In this paper, we examine the effectiveness of the preferential collateral treatment of green bonds in an augmented RBC-model. Preferential treatment stimulates investment into green bonds. However, this only partially transmits to investment into green technologies due to an increase in green firms' leverage and default risk. In a calibration to euro area data, we find that this policy can be fairly powerful in addressing environmental policy concerns, but is still considerably less effective than Pigouvian taxes. Due to the adverse effects on firm risk-taking, the optimal collateral framework features only a small degree of preferential treatment, but still increases welfare. Preferential treatment is a qualitatively and quantitatively imperfect substitute for Pigouvian taxes and is only optimal if Pigouvian taxes cannot be set to their optimal level. If the optimal tax is implemented, the optimal collateral framework is characterized by a symmetric relaxation to solve the trade-off between the benefits of higher collateral supply and the costs of higher risk-taking.

Our results can be read as a call for (i) central bank action if tax policy is not able to adequately address pollution and climate change externalities, (ii) a careful calibration of preferential treatment that takes into account the side effects on firm risk-taking, and (iii) coordination between direct tax policy and central bank collateral policy, to mitigate adverse effects that environmental policy can inflict on the aggregate collateral supply.

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[18] For a tax above the optimal value, the collateral framework optimally treats conventional bonds more preferentially to correct for an overly ambitious environmental policy.

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A Model Appendix

A.1 Bank Liquidity Management Costs

In the quantitative analysis, we assume that banks incur liquidity management costs $\Omega(\overline{b}^i_{t+1})$, which gives rise to collateral premia. In this section, we demonstrate that the resulting first order conditions for corporate bonds are observationally equivalent to the most common micro-foundation used in this context, which are stochastic bank deposit withdrawals, see Corradin et al. (2017), De Fiore et al. (2019), Piazzesi and Schneider (2021), or Bianchi and Bigio (2022). The standard modeling device in this literature is a two sub-period structure, where banks participate in asset markets sequentially: in the first sub-period, banks trade with households on the deposit market and with intermediate good firms on the corporate bond market. In the second sub-period, bank i faces a liquidity deficit $\omega^i_t > 0$, which it settles on a collateralized short-term funding market, e.g., with the central bank.

If bank i is unable to collateralize its entire funding need, it must borrow on the (more expensive) unsecured segment. More specifically, since all banks hold the same amount of collateral $\overline{b}_{t+1}$ before the deposits are withdrawn, there is a cut-off withdrawal $\overline{\omega}_t = \overline{b}_{t+1}$ above which a bank needs to tap the unsecured segment. The amount borrowed on the unsecured segment for all banks follows as

$$\widetilde{b}_{t+1} \equiv \int_{\overline{b}_{t+1}}^{\infty} \left(\omega^i_{t+1} - \overline{b}_{t+1}\right) dW(\omega)\,,$$

where W denotes the cdf of the withdrawal shock distribution. Due to its analytical tractability, it is convenient to assume that withdrawals follow a Lomax distribution. This distribution is supported on the right half-line and characterized by a shape $\widetilde{\alpha}$ and a scale $\widetilde{\lambda}$ parameter. This allows us to write the expected amount of borrowing on the unsecured segment in closed form:

$$\begin{aligned}
\widetilde{b}_{t+1} &= \int_{\overline{b}_{t+1}}^{\infty} \omega^i_{t+1} \frac{\widetilde{\alpha}}{\widetilde{\lambda}} \left(1 + \frac{\omega^i_{t+1}}{\widetilde{\lambda}}\right)^{-\widetilde{\alpha}-1} d\omega - \overline{b}_{t+1} \int_{\overline{b}_{t+1}}^{\infty} \frac{\widetilde{\alpha}}{\widetilde{\lambda}} \left(1 + \frac{\omega^i_{t+1}}{\widetilde{\lambda}}\right)^{-\widetilde{\alpha}-1} d\omega \\
&= \overline{b}_{t+1} \left(1 + \frac{\overline{b}_{t+1}}{\widetilde{\lambda}}\right)^{-\widetilde{\alpha}} + \frac{\widetilde{\lambda}}{\widetilde{\alpha}-1} \left(1 + \frac{\overline{b}_{t+1}}{\widetilde{\lambda}}\right)^{-\widetilde{\alpha}+1} - \overline{b}_{t+1} \left(1 + \frac{\overline{b}_{t+1}}{\widetilde{\lambda}}\right)^{-\widetilde{\alpha}} \\
&= \frac{\widetilde{\lambda}}{\widetilde{\alpha}-1} \left(1 + \frac{\overline{b}_{t+1}}{\widetilde{\lambda}}\right)^{-\widetilde{\alpha}+1} .
\end{aligned}$$

When $\widetilde{\alpha} > 1$, the aggregate amount of unsecured borrowing falls, the more collateral is held. The benefit of holding collateral corresponds to the secured-unsecured spread ξ that is paid on borrowing $\widetilde{b}_{t+1}$, which we assume to be an exogenous parameter. These expected cost $\xi \widetilde{b}_{t+1}$

enter bank profits in the first sub-period

$$\Pi_t^i = d_{t+1}^i - q_{c,t+1}b_{c,t+1}^i - q_{g,t+1}b_{g,t+1}^i - \xi \widetilde{b}_{t+1} \ .$$

The cost depend negatively on $\overline{b}_{t+1}$, but the marginal cost reduction is falling in $\overline{b}_{t+1}$. Since very large withdrawal shocks are unlikely, the additional benefit of holding another unit of collateral is positive but decreasing. The properties of our concave liquidity cost function $\Omega(\overline{b}_{t+1}^i)$ are closely related to the common micro-foundation using bank liquidity risk.

A.2 Intermediate Good Firms

We start with observing that the default threshold of a type-τ intermediate good firm in period $t+1$ is given by $\overline{m}_{\tau,t+1} \equiv \frac{sb_{\tau,t+1}}{(1-\chi_\tau)p_{\tau,t+1}k_{\tau,t+1}}$. The threshold satisfies the following properties:

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

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

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

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

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

Note that the derivative of the conditional mean $g(\overline{m}_{\tau,t+1})$ satisfies

$$g(\overline{m}_{\tau,t+1}) = \overline{m}_{\tau,t+1} f(\overline{m}_{\tau,t+1}) \ . \tag{A.3}$$

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

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

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

$$q(\overline{m}_{\tau,t+1}) = \mathbb{E}_t \frac{s\left(\frac{G(\overline{m}_{\tau,t+1})}{\overline{m}_{\tau,t+1}} + 1 - F(\overline{m}_{\tau,t+1})\right) - F(\overline{m}_{\tau,t+1})\varphi + (1-s)q_{\tau,t+1}}{(1+(1-\phi_\tau)\Omega_{b,t})(1+i_t)}\,. \tag{A.4}$$

The derivative with respect to the default threshold is given by

$$q'(\overline{m}_{\tau,t+1}) = \mathbb{E}_t \frac{-\frac{sG(\overline{m}_{\tau,t+1})}{\overline{m}^2_{\tau,t+1}} - \varphi f(\overline{m}_{\tau,t+1})}{(1+(1-\phi_\tau)\Omega_{b,t})(1+i_t)}\,. \tag{A.5}$$

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

$$\begin{aligned}
0 =& q'(\overline{m}_{\tau,t+1})\frac{\partial \overline{m}_{t+1}}{\partial b_{\tau,t+1}}\Big(b_{\tau,t+1} - (1-s)b_{\tau,t}\Big) + q(\overline{m}_{\tau,t+1}) \\
&+ \mathbb{E}_t\Bigg[\widetilde{\Lambda}_{t,t+1}\Bigg(-(1-\chi_\tau)p_{\tau,t+1}k_{\tau,t+1}G'(\overline{m}_{\tau,t+1})\frac{\partial \overline{m}_{\tau,t+1}}{\partial b_{\tau,t+1}} \\
&\quad - s\Big(-f(\overline{m}_{\tau,t+1})\frac{\partial \overline{m}_{\tau,t+1}}{\partial b_{\tau,t+1}}b_{\tau,t+1} + 1 - F(\overline{m}_{\tau,t+1})\Big) - q_{\tau,t+1}(1-s)\Bigg)\Bigg]\,,
\end{aligned}$$

which can be expressed as

$$\begin{aligned}
0 =& q'(\overline{m}_{\tau,t+1})\frac{\mathbb{E}_t[\overline{m}_{\tau,t+1}]}{b_{\tau,t+1}}\Big(b_{\tau,t+1} - (1-s)b_{\tau,t}\Big) + q(\overline{m}_{\tau,t+1}) \\
&+ \mathbb{E}_t\Bigg[\widetilde{\Lambda}_{t,t+1}\Bigg(-sG'(\overline{m}_{\tau,t+1})\frac{\overline{m}_{\tau,t+1}(1-\chi_\tau)p_{\tau,t+1}k_{\tau,t+1}}{sb_{\tau,t+1}} \\
&\quad - s\Big(-f(\overline{m}_{\tau,t+1})\overline{m}_{\tau,t+1} + 1 - F(\overline{m}_{\tau,t+1})\Big) - q_{\tau,t+1}(1-s)\Bigg)\Bigg]\,,
\end{aligned}$$

and then yields (14).

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

$$\begin{aligned}
1 =& q'(\overline{m}_{\tau,t+1})\frac{\partial \overline{m}_{\tau,t+1}}{\partial k_{\tau,t+1}}\Big(b_{\tau,t+1} - (1-s)b_{\tau,t}\Big) \\
&+ \mathbb{E}_t\Bigg[\widetilde{\Lambda}_{t,t+1}\Bigg(-G'(\overline{m}_{\tau,t+1})\frac{\partial \overline{m}_{\tau,t+1}}{\partial k_{\tau,t+1}}(1-\chi_\tau)p_{\tau,t+1}k_{\tau,t+1} + (1-G(\overline{m}_{\tau,t+1}))(1-\chi_\tau)p_{\tau,t+1} \\
&\quad + sb_{\tau,t+1}f(\overline{m}_{\tau,t+1})\frac{\partial \overline{m}_{\tau,t+1}}{\partial k_{\tau,t+1}} + 1 - \delta\Bigg)\Bigg]\,,
\end{aligned}$$

which can be rearranged to

$$
\begin{aligned}
1 = &-q'(\overline{m}_{\tau,t+1})\frac{\mathbb{E}_t[\overline{m}_{\tau,t+1}]}{k_{\tau,t+1}}\Big(b_{\tau,t+1}-(1-s)b_{\tau,t}\Big) \\
&+\mathbb{E}_t\Bigg[\widetilde{\Lambda}_{t,t+1}\Bigg(G'(\overline{m}_{\tau,t+1})\overline{m}_{\tau,t+1}(1-\chi_\tau)p_{\tau,t+1}+\big(1-G(\overline{m}_{\tau,t+1})\big)(1-\chi_\tau)p_{\tau,t+1} \\
&\qquad -sb_{\tau,t+1}f(\overline{m}_{\tau,t+1})\frac{\overline{m}_{\tau,t+1}}{k_{\tau,t+1}}\frac{(1-\chi_\tau)p_{\tau,t+1}}{(1-\chi_\tau)p_{\tau,t+1}}+1-\delta\Bigg)\Bigg] ,
\end{aligned}
$$

and further to (15).

A.3 Collateral Default Costs

In the main text we assume an exogenous cost function from collateral default $\Lambda(\overline{F}_t)$. In this section, we provide a micro-foundation based on central bank solvency concerns (see Hall and Reis, 2015). We show that this yields a loss function $\Lambda(\overline{F}_t)$, which is increasing in $\overline{F}_t$, consistent with our assumption in the main text. Similar to Appendix A.1, assume that banks incur a fixed liquidity shock in every period ω, which they settle by borrowing from the central bank. Since the collateral banks pledge is subject to default risk, the central bank will subject itself to these risks when entering repurchase agreements. The central bank haircut ϕ directly affects exposure to this risk. The timing is as follows: in the beginning of period t, banks invest into risky bonds. In the end of period t, they incur the exogenous liquidity need and tap the central bank facility. Repos mature in the beginning of period $t+1$ and banks repay the central bank. Each bank holds corporate bonds b_{t+1} at price q_t and borrows

$$
\omega = (1-\phi)q_t b_{t+1} ,
$$

from the central bank. Because every bank i incurs the liquidity shock, i indexes both banks and repo contracts. We assume that bank default can be represented by the i.i.d. random variable ζ^i with cdf Z and pdf z, and with support $[0,1]$. The bond-specific default risk is denoted F_t. In case of a bank default, the central bank seizes the posted collateral to cover its losses. However, since the collateral itself defaults at rate F_t, the central bank will not recover the full amount of the defaulted repo. The expected loss on repo i follows as

$$
\mathcal{F}_t^i = \zeta^i \cdot \omega \cdot F_t = \zeta^i \cdot (1-\phi)q_t b_{t+1} \cdot F_t .
$$

To make the results more easily interpretable, it is helpful to assume central bank also generates seigniorage revenues from lending through its facilities. As customary in the literature, we assume that seigniorage revenues are bounded from above by the (time-invariant) constant $\mathcal{M}$.

Consequently, the central bank incurs a loss from bank default if the default shock exceeds $\overline{\zeta}_t = \mathcal{M}/(\omega \cdot F_t)$. We can then denote the expected central bank loss as

$$\mathcal{L}_t = \int_{\overline{\zeta}_t}^{1} \zeta^i \cdot (1-\phi) q_t b_{t+1} \cdot F_t \cdot z(\zeta) d\zeta = (1-\phi) q_t b_{t+1} F_t \cdot \int_{\overline{\zeta}_t}^{1} \zeta^i z(\zeta) d\zeta \,. \tag{A.6}$$

The central bank haircut and bond default risk affect the expected loss in two ways. The first part of (A.6) show that irrespective of the distributional assumption on ζ^i, the expected loss rises in bond default risk F_t and that a higher haircut ϕ, by lowering the repo size, reduces cost. Second, note that $\overline{\zeta}_t = \mathcal{M}/((1-\phi) q_t b_{t+1} \cdot F_t)$. A higher haircut increases the default risk threshold beyond which central bank income is negative. Thus, it lowers the expected loss. Conversely, higher bond default risk increases expected cost. Defining collateral default risk as the repo size-weighted default risk $\overline{F}_t = (1-\phi) q_t b_{t+1} F_t$, this behavior is directly reflected in $\Lambda(\overline{F}_t)$ in the main text.

B Additional Numerical Results

B.1 The Role of the Green-Conventional Substitution Elasticity

In Table B.1, we provide robustness checks regarding the production technology of wholesale goods producers. By assuming a Cobb-Douglas production function in (8), we implicitly assume an elasticity of substitution of one between green and conventional intermediate goods. When strictly interpreting green and conventional firms as energy producers, this elasticity is usually estimated to be larger than one. Therefore, we repeat our policy analysis when replacing the wholesale producers' technology by a general CES-function

$$z_t = \left(\nu z_{g,t}^{\frac{\varepsilon_\nu - 1}{\varepsilon_\nu}} + (1-\nu) z_{c,t}^{\frac{\varepsilon_\nu - 1}{\varepsilon_\nu}} \right)^{\frac{\varepsilon_\nu}{\varepsilon_\nu - 1}} , \tag{A.7}$$

and set the elasticity of substitution $\varepsilon_\nu = 1.6$, following the point estimate in Papageorgiou et al. (2017). The parameter ν is set to keep the green production share at 20%, consistent with the baseline. Results are shown in Table B.1. To ensure an apples-to-apples comparison with the baseline model, we re-calibrate the idiosyncratic productivity variance to $\varsigma_M = 0.195$, the firm owners' discount factor $\widetilde{\beta} = 0.984$, the externality parameter $\gamma_P = 0.015$, the slope parameter $\eta_1 = 0.0432$ in the collateral default cost function, and the slope parameter $l_1 = 0.008$ in the liquidity management cost function. While the main results from the Cobb-Douglas baseline carry over to the CES case, the optimal tax is much higher and optimal collateral policy implies a much larger degree of preferential treatment. Intuitively, when conventional and green intermediate goods are easier to substitute, any policy-induced reduction in the size

Table B.1: Time Series Means with $\varepsilon_v = 1.6$

Moment	Baseline	Max Pref	Opt Coll	Only Tax	Glob Opt
Tax Parameter χ_c	0	0	0	12.5%	12.5%
Haircut ϕ_g	26%	0%	5%	26%	18%
Haircut ϕ_c	26%	100%	31%	26%	18%
Welfare Change (CE)	0%	-0.5450%	+0.0135%	+1.1560%	+1.1577%
Conv. Leverage	39.7%	38.7%	39.7%	39.7%	39.7%
Green Leverage	39.7%	40.4%	39.9%	39.7%	39.7%
Conv. Bond Spread	97bp	157bp	101bp	97bp	94bp
Green Bond Spread	97bp	16bp	81bp	97bp	94bp
Conv. Coll. Premium	-11bp	0bp	-10bp	-11bp	-11bp
Green Coll. Premium	-11bp	-26bp	-14bp	-11bp	-11bp
GDP	0.8253				
Change from Baseline	-	+0.14%	+0.03%	+1.01%	+1.05%
Restructuring Cost/GDP	2.17%				
Change from Baseline	-	-20.38%	+0.13%	-0.23%	+2.42%
Coll. Default Cost/GDP	1.52%				
Change from Baseline	-	-28.56%	+0.81%	-0.62%	+6.46%
Liq. Man. Cost/GDP	3.29%				
Change from Baseline	-	+37.57%	-0.28%	-1.40%	-6.35%
Pollution Cost/GDP	9.81%				
Change from Baseline	-	-1.79%	-0.14%	-16.17%	-16.06%
Green Bond Share	20.49%	22.24%	20.73%	34.57%	34.56%
Green Capital Share	20.49%	21.52%	20.64%	34.57%	34.56%

Notes: Maximal preferential treatment (*Max Pref*) only allows green bonds as collateral ($\phi_g = 0, \phi_c = 1$). The optimal collateral policy (*Opt Coll*) is derived from maximizing CE over a grid of haircuts. For the optimal tax (*Only Tax*), we hold haircuts fixed and vary the tax rate. The global optimum (*Glob Opt*) is obtained by maximizing over taxes and haircuts.

of conventional firms is less harmful to production.

B.2 The Role of Nominal Rigidities

In this section, we add nominal rigidities to the model following the standard New Keynesian model. In particular, bonds are assumed to be denominated in nominal terms, i.e., inflation has a direct effect on corporate bonds and the supply side. Households consume a final goods basket c_t given by

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

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

$$c_{j,t} = \left(\frac{P_{j,t}}{P_t}\right)^{-\varepsilon} c_t \,, \tag{A.8}$$

where P_t denotes the CES price index for the final consumption bundle. Final good firms sell their differentiated good with a markup over their marginal costs. However, the price of firm j, $P_{j,t}$, 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 j's marginal costs are denoted by $\mathrm{mc}_{j,t} \equiv \partial \mathcal{C}_t^W / \partial y_{j,t}$, where the wholesale firm's cost minimization problem is given by

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

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

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

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 j in period t are given by

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

where ψ measures the degree of the nominal rigidity. Each wholesale good firm j maximizes the expected sum of discounted profits

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

subject to the demand schedule (A.8). Plugging in the demand function yields the first order condition

$$\begin{aligned}
&\left(\frac{P_{j,t}}{P_t}\right)^{-\varepsilon} Y_t - \varepsilon \left(P_{j,t} - \mathrm{mc}_t P_t\right) \left(\frac{P_{j,t}}{P_t}\right)^{-\varepsilon} \frac{y_t}{P_t} - \psi \left(\frac{P_{j,t}}{P_{j,t-1}} - 1\right) \frac{P_t}{P_{j,t-1}} y_t \\
&+ \mathbb{E}_t \left[\frac{c_{t+1}^{-\gamma_c}/P_{t+1}}{c_t^{-\gamma_c}/P_t} \psi \left(\frac{P_{j,t+1}}{P_{j,t}} - 1\right) \frac{P_{j,t+1}}{P_{j,t}^2} P_{t+1} y_{t+1} \right] = 0 \,.
\end{aligned}$$

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

$$(1-\varepsilon(1-\mathrm{mc}_t))\,y_t + \mathbb{E}_t\left[\beta \frac{c_{t+1}^{-\gamma_c}/P_{t+1}}{c_t^{-\gamma_c}/P_t} y_{t+1}\pi_{t+1}\psi\left(\pi_{t+1}-1\right)\pi_{t+1}\right] = \psi\left(\pi_t - 1\right)\pi_t y_t \ ,$$

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

$$\mathbb{E}_t\left[\beta \frac{c_{t+1}^{-\gamma_c}/P_{t+1}}{c_t^{-\gamma_c}/P_t}\frac{y_{t+1}\pi_{t+1}}{y_t}\left(\pi_{t+1}-1\right)\pi_{t+1}\right] + \frac{\varepsilon}{\psi}\left(\mathrm{mc}_t - \frac{\varepsilon-1}{\varepsilon}\right) = \left(\pi_t - 1\right)\pi_t \ .$$

In addition, nominal rigidities also affect intermediate good firms, since inflation affects the default threshold $\overline{m}_{\tau,t+1} \equiv \frac{sb_{\tau,t+1}}{\pi_{t+1}(1-\chi_\tau)p_{\tau,t+1}k_{\tau,t+1}}$ and the *real per-unit* bond payoff is

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

Their first order conditions are now given by

$$\begin{aligned} q'(\overline{m}_{\tau,t+1})&\frac{\mathbb{E}_t[\overline{m}_{\tau,t+1}]}{b_{\tau,t+1}}\left(b_{\tau,t+1} - (1-s)\frac{b_{\tau,t}}{\pi_t}\right) + q(\overline{m}_{\tau,t+1}) \\ &= \widetilde{\beta}\mathbb{E}_t\left[\widetilde{\Lambda}_{t,t+1}\frac{s(1-F(\overline{m}_{\tau,t+1})) + (1-s)q_{\tau,t+1}}{\pi_{t+1}}\right] \end{aligned}$$

and

$$\begin{aligned} 1 = &-q'(\overline{m}_{\tau,t+1})\frac{\mathbb{E}_t[\overline{m}_{\tau,t+1}]}{k_{\tau,t+1}}\left(b_{\tau,t+1} - (1-s)\frac{b_{\tau,t}}{\pi_t}\right) \\ &+ \mathbb{E}_t\left[\widetilde{\Lambda}_{t,t+1}\left(\widetilde{\beta}(1-\delta) + \widetilde{\beta}(1-\chi_\tau)p_{\tau,t+1}\left(1-G(\overline{m}_{\tau,t+1})\right)\right)\right] . \end{aligned}$$

The resource constraint now also includes Rotemberg costs

$$y_t = c_t + \sum_\tau (c_{\tau,t} + i_{\tau,t}) + \Lambda(\overline{F}_{t+1}) + \Omega(\overline{b}_{t+1}) + \frac{\psi}{2}\left(\pi_t - 1\right)^2 y_t + \sum_\tau \varphi F(\overline{m}_{\tau,t})\frac{b_{\tau,t}}{\pi_t} \ .$$

To close the model, we assume that the central bank sets i_t according to a Taylor rule

$$i_t = i\pi_t^{\phi_\pi} \ . \tag{A.9}$$

We choose standard parameters for the final goods elasticity $\varepsilon = 6$, implying a markup of 20% in the deterministic steady state, and a Rotemberg parameter $\psi = 57.8$, consistent with a Calvo

Table B.2: Time Series Means with Nominal Rigidities

Moment	Baseline	Max Pref	Opt Coll	Only Tax	Glob Opt
Tax Parameter χ_c	0	0	0	10%	10%
Haircut ϕ_g	26%	0%	7%	26%	19%
Haircut ϕ_c	26%	100%	31%	26%	19%
Welfare Change (CE)	0%	-0.4608%	0.0088%	0.6979%	0.6987%
Conv. Leverage	42.1%	41.4%	42.1%	42.1%	42.1%
Green Leverage	42.1%	42.5%	42.2%	42.1%	42.1%
Conv. Bond Spread	96bp	162bp	100bp	96bp	94bp
Green Bond Spread	96bp	2bp	80bp	96bp	94bp
Conv. Coll. Premium	-11bp	0bp	-10bp	-11bp	-11bp
Green Coll. Premium	-11bp	-27bp	-14bp	-11bp	-11bp
GDP	0.6869				
Change from Baseline	-	+0.00%	+0.02%	+0.60%	+0.64%
Restructuring Cost/GDP	1.92%				
Change from Baseline	-	-20.22%	-0.04%	-0.14%	+1.96%
Coll. Default Cost/GDP	1.48%				
Change from Baseline	-	-29.68%	+0.26%	-0.37%	+5.36%
Liq. Man. Cost/GDP	4.79%				
Change from Baseline	-	+23.88%	+0.03%	-0.75%	-3.25%
Pollution Cost/GDP	9.95%				
Change from Baseline	-	-1.69%	-0.10%	-9.02%	-8.92%
Inflation Volatility	0.10%				
Change from Baseline	-	-7.73%	-0.05%	+0.49%	+0.51%
Green Bond Share	20.00%	21.17%	20.15%	28%	28%
Green Capital Share	20.00%	20.74%	20.09%	28%	28%

Notes: Maximal preferential treatment (*Max Pref*) only allows green bonds as collateral ($\phi_g = 0, \phi_c = 1$). The optimal collateral policy (*Opt Coll*) is derived from maximizing welfare over haircuts. For the optimal tax (*Only Tax*), we hold haircuts fixed and vary the tax rate. The global optimum (*Glob Opt*) is obtained by maximizing over taxes and haircuts.

parameter of 0.75. The parameter on inflation stabilization in the monetary policy rule is set to $\phi_\pi = 5$, which ensures determinacy for all policy experiments. We slightly re-calibrate the slope parameter $\eta_1 = 0.0407$ in the collateral default cost function, and the slope parameter $l_1 = 0.007$ in the liquidity management cost function. Results are reported in Table B.2 and show very similar implications for optimal collateral policy and its interaction with Pigouvian taxation.[19] In particular, the inflation volatility under optimal preferential treatment is almost unchanged with respect to the baseline in column one, alleviating concerns that preferential treatment jeopardizes price stability, the central bank's primary policy objective.

[19]We only observe small differences in the reactions of the cost terms for optimal collateral policy. The haircut on conventional bonds increases by more compared to the main text. As a result, liquidity management costs rise and costs from debt restructuring fall.

C Yield Reaction to Central Bank Policy Announcements

C.1 Construction of the 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. To identify relevant speeches for our empirical analysis, we rely on a dataset published by the ECB that contains date, title (including sub-titles), speaker, content, and footnotes of nearly all speeches by presidents and board members since 1999 (see European Central Bank, 2021b). 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 for a wrong positive (e.g., *environment* refers to low interest rates).
- We exclude speeches that address climate risk or transition risk.
- Speeches within 20 trading days of the previous speech are excluded to avoid overlapping treatment periods.

We exclude communication that refer to *climate risk* and *transition risk*, since these refer to improving disclosure standards, the extent to which climate risk should be considered in credit risk assessment, and asset stranding. These issues are important for the conduct of central bank policy in general, but do not specifically address bond markets. This leaves us with four speeches. Table C.1 contains details regarding the key content that motivates our classification.

Table C.1: Relevant ECB Policy Announcements

Date	**Person**	**Link**	**Relevant Quotes**
08-11-2018	Benoît Cœuré	ECB	• (...) 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. • Purchasing green bonds (...) could be an option, as long as the markets are deep and liquid enough.
27-02-2020	Christine Lagarde	ECB	• (...) reviewing the extent to which climate-related risks are understood and priced by the market (...) • (...) evaluate the implications for our own management of risk, in particular through our collateral framework.
17-07-2020	Isabel Schnabel	ECB	• (...) way in which we can contribute is by taking climate considerations into account when designing and implementing our monetary policy operations. • (...) Of course, central banks would need to be mindful of their effects on market functioning. • (...) severe risks to price stability, central banks are required, within their traditional mandates, to strengthen their efforts (...)
21-09-2020	Christine Lagarde	ECB	• We cannot miss this opportunity to reduce and prevent climate risks and finance the necessary green transition. • The ECB's ongoing strategy review will ensure that its monetary policy strategy is fit for purpose (...) • (...) Jean Monnet's words, (...) opportunity for Europe to take a step towards the forms of organisation of the world of tomorrow.

Notes: Speeches are taken from European Central Bank (2021b).

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". Since many green bonds do not show up in the *IHS Markit* database, we additionally obtain data from *Thomson Reuters Datastream*. We match green and conventional bonds *one trading-day before* each announcement date using a nearest-neighbors procedure involving coupon, bid-ask spread, maturity, notional amount, and yield spreads. Specifically, 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.2 contains summary statistics regarding the matching. Coupon and bid-ask spreads are very similar for both types of bonds. Spreads of green bonds are higher by between 5 and 8bp, while their maturity is higher by 1.5 years on average.

Table C.2: 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
27-02-2020	83	0.36	0.32	1.18	1.15	51.66	44.82	6.7	5.2	695	690
17-07-2020	77	0.45	0.38	1.22	1.22	77.49	72.00	6.6	4.9	693	689
21-09-2020	79	0.38	0.36	1.18	1.14	64.94	56.68	6.3	4.6	701	709

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

C.2 Yield Reactions

In Figure C.1, we display the average response across treatment dates. The greenium becomes significant two trading days after each announcement and widens to around 16 bp after 20 trading days.

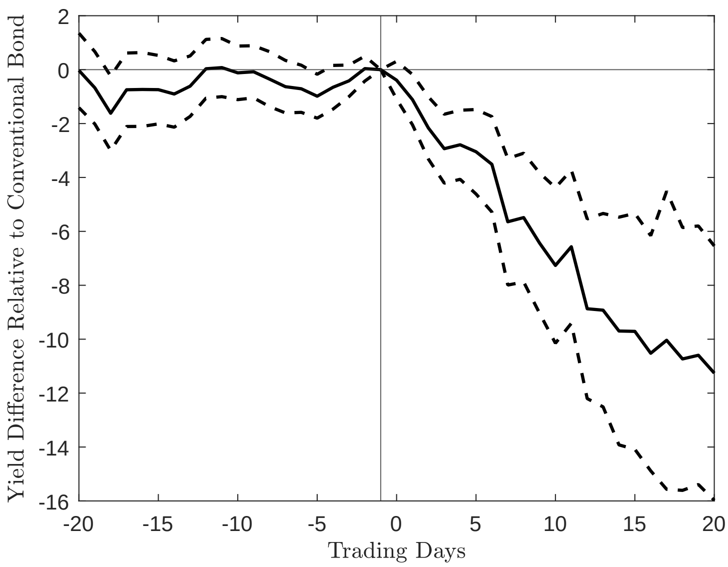

Figure C.1: Average Yield Reaction around Treatment Window

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

Table C.3 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 on February 27^{th} 2020, which included the first explicit reference to the ECB's collateral framework. Moreover, the speech delivered by Isabel Schnabel on July 17^{th} 2020 stands out, since yields on green bonds significantly increased compared to their conventional counterparts 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.[20]

Table C.3: Yield Reaction Around ECB Policy Announcements

Date	**Type**	**Yield Reaction**	**Standard Error**
08-11-2018	Board Member Speech	-7.9***	1.78
27-02-2020	President Speech	-19.4***	3.89
17-07-2020	Board Member Speech	6.8***	1.67
21-09-2020	President Speech	1.3	1.23

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 five speeches that are unrelated to environmental policy in Table C.4. We do not find any significantly negative effects and conclude that the overall impact of ECB environmental policy announcement is unlikely to be explained by a general negative trend in the greenium.

Table C.4: Yield Reaction Around Non-Related ECB Policy Announcements

Date	**Type**	**Yield Reaction**	**Standard Error**
01-10-2019	President Speech (ECB)	1.61**	0.82
06-11-2019	Board Member Speech (ECB)	0.77	0.69
16-12-2019	Board Member Speech (ECB)	5.06***	0.80
10-06-2020	Board Member Speech (ECB)	3.39*	2.54
27-08-2020	Board Member Speech (ECB)	1.64**	0.81

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 Data Sources

Table D.1 summarizes the data sources on which our empirical analysis and calibration are 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

[20]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*”.

info from Datastream. Data on conventional bonds in the control group is taken from Markit. EURIBOR data are also obtained through Datastream. We use the ECB to obtain data on non-financial firm debt, GDP, employment, gross fixed capital formation, private consumption, and the GDP deflator.

Table D.1: Data Sources and Ticker

Series	**Source**	**Mnemonic**
Green Bond List I	Euronext	List retrieved Nov-30-2020
Green Bond List II	Frankfurt SE	List retrieved Nov-30-2020
Green Bond List III	Vienna SE	List 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 (... = maturity)	Datastream	TRE6S...Y
Debt-to-GDP	ECB	QSA.Q.N.I8.W0.S11.S1.C.L.LE.F3T4.T._Z.XDC_R_B1GQ_CY._T.S.V.N._T
Markit iBoxx Components	IHS Markit	-
GDP	ECB	MNA.Q.Y.I8.W2.S1.S1.B.B1GQ._Z._Z._Z.EUR.V.N
Gross fixed capital formation	ECB	MNA.Q.Y.I8.W0.S1.S1.D.P51G.N11G._T._Z.EUR.V.N
Consumption	ECB	MNA.Q.Y.I8.W0.S1M.S1.D.P31._Z._Z._T.EUR.V.N
GDP Deflator	ECB	MNA.Q.Y.I8.W2.S1.S1.B.B1GQ._Z._Z._Z.IX.D.N
Employment	ECB	ENA.Q.Y.I8.W2.S1.S1._Z.EMP._Z._T._Z.PS._Z.N