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Greening the output floor:
an agent-based credit network analysis

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Abstract

This paper investigates the prudential and environmental implications of an environmentally targeted output floor. We extend an agent-based credit-network model by distinguishing brown and green non-financial corporate exposures and incorporating pollution dynamics and climate damages. We compare the standard Basel output floor with a brown output floor not applied to green non-financial corporate exposures. Both designs significantly affect banks' Risk-Weighted Asset (RWA) densities, while the brown output floor preserves the reduction in RWA-density dispersion among IRB banks achieved by the standard regulation. Neither policy significantly contracts non-financial corporate lending, as banks adjust primarily through the interbank market. While the standard output floor is associated with significant increases in emissions and pollution relative to the no-output-floor benchmark, no statistically significant environmental deterioration emerges under the brown output floor. These results suggest that environmental targeting may reconcile prudential discipline with green-transition objectives.

Keywords: Output Floor; Climate-Related Financial Risks; Green Prudential Policy; Credit Network.
JEL classification: G21; G28; Q54; C63.

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1 Introduction

The need to accelerate the transition towards a low-carbon economy has raised growing concerns about the ability of the financial system to support environmental objectives while remaining resilient to climate-related risks. Carbon-intensive activities contribute to the accumulation of physical climate risks, which can impair firms' productive capacity, increase default risk, and ultimately weaken the balance sheets of their lending banks. In response, academics and policymakers have considered whether prudential regulation should move beyond its traditional objective of financial stability and incorporate the environmental characteristics of bank exposures (D'Orazio and Popoyan, 2019 ; Dafermos and Nikolaidi, 2021). This debate has become particularly relevant as banks continue to play a central role in financing both polluting activities and the investments required for the green transition.

Most proposals for climate-sensitive prudential regulation have focused on differentiated capital requirements for green and brown exposures. A Green Supporting Factor would reduce the regulatory risk weights applied to environmentally sustainable assets, whereas a Brown Penalizing Factor would increase those associated with carbon-intensive activities. Although these instruments may influence the allocation of bank credit, both raise important prudential concerns. The former may lead banks to underestimate the financial risks associated with some green projects, while the latter may increase capital requirements and restrict aggregate credit during the transition (Matikainen, 2017 ; Van Lerven and Ryan-Collins, 2018 ; D'Orazio and Popoyan, 2019). Moreover, existing studies suggest that these instruments may generate only limited environmental improvements in the absence of complementary climate policies (Dafermos and Nikolaidi, 2021 ; Oehmke and Opp, 2023).

The Basel III output floor offers an alternative framework within which climate considerations could be incorporated into banking regulation. In Europe, under the standard output floor, the Risk-Weighted Assets (RWA) calculated by banks using internal models cannot fall below 72.5 percent of the amount obtained under the standardized approach (BCBS, 2017). By limiting excessive reliance on internal risk estimates, this regulation is intended to reduce unwarranted variability in RWA and improve the comparability of capital ratios across banks. However, because the standard output floor applies uniformly to green and brown exposures, it does not explicitly account for their different contributions to climate change. A brown output floor, applying the constraint specifically to internally estimated risk weights on carbon-intensive non-financial corporate loans, could therefore preserve the prudential rationale of the standard regulation while introducing an environmental dimension into its design.

This paper investigates whether such a targeted output floor can simultaneously promote the decarbonization of the economy and maintain prudential discipline. More specifically, we examine whether the brown output floor reduces aggregate emissions by affecting the financing conditions, technological choices, and abatement decisions of polluting firms, while limiting the variability and cross-sectional dispersion of banks' RWA density ratios, as expected under the standard output floor.

To address this question, we develop an environmental agent-based credit-network model populated by heterogeneous banks and green and brown firms. The framework incorporates endogenous firm defaults, bank-specific choices between the standardized and Internal Ratings-Based (IRB) approaches, stochastic firm-level climate damages, emissions taxation, and endogenous abatement. It therefore allows us to compare the financial and environmental effects of the standard and brown output floors while accounting for the nonlinear interactions between bank regulation, credit allocation, firm behavior, and climate risk.

Our results highlight important differences between the standard and brown output floors. Both regulatory designs significantly affect the distribution of RWA density, with particularly pronounced effects among IRB banks, which are directly subject to the output-floor constraint. In particular, the brown output floor preserves the reduction in RWA-density dispersion among IRB banks achieved by the standard output floor, with no statistically significant difference between the two policies along this dimension. At the system-wide level, however, the reduction in RWA-density dispersion is slightly but significantly smaller under the brown output floor, reflecting a composition effect arising from the heterogeneous responses of IRB and SA banks. Despite the resulting tightening of regulatory risk, neither output-floor design generates a significant contraction in non-financial corporate lending. Banks instead adjust primarily through the interbank market, suggesting that the regulatory constraint mainly reshapes the composition of credit within the banking network rather than inducing a generalized contraction in financing to the real economy.

The environmental effects reveal an additional distinction between the two regulatory designs. The standard output floor is associated with statistically significant increases in emissions and the pollution stock relative to the no-output-floor benchmark, together with weak evidence of an increase in brown non-financial corporate lending. By contrast, no statistically detectable increase in brown non-financial corporate lending, emissions, or pollution emerges under the brown output floor. At the same time, the targeted regulation shifts part of the distribution of brown non-financial corporate RWA density toward higher values among IRB banks, consistent with the intended mechanism of the brown output floor. Taken together, these findings suggest that environmentally targeting the output floor may mitigate potential tensions between prudential discipline and the green transition while preserving its effectiveness in reducing RWA-density dispersion among directly affected banks. However, since the environmental outcomes under the standard and brown output floors are not statistically different from each other, our results should not be interpreted as establishing the superiority of the brown design, but rather as evidence that environmental targeting may provide a different balance between prudential and environmental objectives.

The remainder of the paper is organized as follows. Section 2 reviews the relevant literature. Section 3 presents the main features and methodological contributions of the model, while Section 4 describes the calibration strategy and the empirical moments used to discipline the model. Section 5 examines the distributional effects of the brown output floor on banks' RWA densities. Section 6 investigates its macroeconomic, macrofinancial, and environmental implications and compares them with those of the standard output floor. Finally, Section 7 concludes.

2 Related literature

The paper first contributes to the literature on bank–firm relationships in agent-based credit networks. Building on Delli Gatti et al.(2010) and Riccetti et al.(2013), the model incorporates a network-based financial accelerator through which firms' balance sheets, credit conditions, and defaults reinforce boom-and-bust cycles and reshape the credit network over time. Unlike frameworks in which each firm is connected to a single bank, firms may establish multiple banking relationships and borrow from several lenders, as in Catullo et al.(2021). The model also includes an interbank market through which bank distress can propagate across the financial network and generate cascading failures (Battiston et al., 2012; Tedeschi et al., 2012; Gurgone et al., 2018). Following Assenza et al. (2018), each bank operates as either a lender or a borrower in this market during a given period, facilitating the identification of interbank flows and the calculation of non-performing interbank exposures.

Our paper also relates to agent-based studies of the effects of bank capital regulation on credit supply. As in D'Orazio (2019), Ermolova et al. (2021), Catullo et al.(2021), and Adão et al.(2022)), banks' leverage and capital constraints influence both the volume and the interest rate of the credit they supply. However, rather than relying on fixed regulatory risk weights, our framework allows them to vary endogenously over time with borrowers' financial conditions. While Chan-Lau (2017) also considers time-varying optimal risk weights, our model explicitly distinguishes between the standardized and IRB approaches in accordance with the Basel III finalization framework. In this respect, it connects the agent-based credit-network literature with structural banking models that incorporate IRB-based capital requirements (Mendicino et al., 2018; Darracq-Paries et al., 2019).

The paper also contributes to the growing literature on environmental agent-based macroeconomic models incorporating credit and banking mechanisms. Ponta et al. (2018) extend the Eurace framework with fossil-fuel and renewable electricity producers to study how feed-in tariffs affect investment, emissions, and macroeconomic performance. Monasterolo and Raberto (2018) develop the EIRIN flow-of-funds behavioural model and show that green fiscal policies and sovereign green bonds can influence firms' expectations and foster green investment through the credit market. Similarly, the agent-based integrated assessment model developed by Lamperti et al. (2019a) captures the co-evolution of innovation, production, emissions, and climate damages, thereby emphasizing the nonlinear feedback effects between technological change and environmental dynamics. Compared with these contributions, our model places greater emphasis on heterogeneous bank–firm relationships and on how the endogenous allocation of credit between green and brown firms affects emissions, firm defaults, and banking-sector fragility.

A closely related strand of behavioural and ecological macro-financial models examines the transmission of physical and transition climate risks through firms' and banks' balance sheets. In an ecological stock-flow-fund consistent framework, Dafermos et al. (2018) show that climate damages can destroy firms' productive capital, reduce their profitability and liquidity, increase defaults, and ultimately weaken banks and credit expansion; they also find that green quantitative easing can mitigate both global warming and climate-induced financial instability. Lamperti et al. (2019b) similarly show, within an agent-based framework, that climate-related damages to firms' productive capacity generate non-financial corporate defaults, bank losses, and more frequent banking crises. Building on this framework, Lamperti et al. (2021) compare alternative green financial policies and demonstrate that their effectiveness depends on the joint response of credit allocation, bank resilience, and firms' technological transition. Dunz et al. (2021) further show that banks' climate sentiments can amplify transition risks through lending conditions, while Gourdel et al. (2024) emphasize the double materiality arising from the effects of climate risks on financial institutions and the contribution of financial decisions to decarbonization. Unlike these contributions, our paper embeds stochastic firm-level climate damages within a bank–firm and interbank credit network and explicitly distinguishes between the standardized and IRB approaches to credit risk. This enables us to assess whether a brown output floor can reduce emissions while preserving the prudential objective of limiting the variability and cross-sectional dispersion of banks' RWA density ratios.

A final strand of literature examines the effects of the Basel III output floor on capital requirements, risk-weight comparability, and banks' portfolio decisions. Using bank-level credit portfolios, Binder and Lehner (2020) show that the output floor is one of the components of the Basel III finalization package with the strongest impact on RWA density, although its ability to reduce heterogeneity depends on the degree of optimism embedded in banks' internal models. Similarly, Pop and Pop (2025) demonstrate that the effectiveness of the floor depends critically on the risk sensitivity of the standardized benchmark: a more granular standardized approach that closely reproduces internal credit assessments reduces the incremental effect of the constraint. From a bank-management perspective, Neisen and Schulte-Mattler (2021) show that banks can mitigate the additional capital burden generated by the floor by adjusting their portfolio composition, pricing policies, and internal capital allocation.

The theoretical literature further investigates the macrofinancial and environmental consequences of the output floor. In an agent-based credit network populated by heterogeneous banks and firms, Roussel (2025) finds that the standard output floor raises average RWA density and reduces its cross-bank dispersion, thereby improving the comparability of capital requirements. Reite (2026) further shows that capital floors may constrain the effectiveness of prudential incentives designed to promote green lending, particularly when internal risk models already incorporate conservative risk assessments. The contribution most closely related to our environmental policy setting is Roussel (2024a), who introduces a brown output floor—applied exclusively to carbon-intensive credit exposures—into a general equilibrium model of the euro area. The results reveal a trade-off between reducing the environmental consequences of bank lending and achieving the conventional prudential objective of stabilizing RWA densities and banks' Capital Adequacy Ratios (CAR). Our paper lies at the intersection of Roussel (2025) and Roussel (2024a): it introduces the environmental differentiation of the output floor developed in the general equilibrium framework into an agent-based credit network with heterogeneous banks and green and brown firms. This approach allows us to examine whether the brown output floor can simultaneously reduce aggregate emissions and limit the cross-sectional dispersion of banks' RWA densities.

3 The Model

The model builds on the framework of Roussel (2025) by distinguishing between polluting ("brown") and non-polluting ("green") loans to non-financial corporations based on firms' environmental behavior, and by introducing an environmental block closely related to the climate modules commonly used in the environmental agent-based modeling literature.

The credit network evolves endogenously and consists of N firms and M banks. The credit market is divided into two segments: non-financial corporate lending and interbank lending.

In the non-financial corporate credit market, banks provide loans to both polluting ("brown") and non-polluting ("green") firms. Upon entry, each new firm chooses whether to operate as a brown or green firm based on the relative profitability and failure rates of surviving brown and green firms in the previous period.[1] At each period t, every firm $n = 1, \ldots, N$ may approach multiple banks, indexed by $m = 1, \ldots, M$, to obtain non-financial corporate loans and, with a given probability, selects those offering the lowest lending rates. In subsequent periods, firms may replace an existing bank relationship with a newly selected bank if the latter offers a lower lending rate than the incumbent bank.

In line with Ferrari and Nispi-Landi (2024), we assume that only brown firms generate emissions, which contribute to the accumulation of an aggregate pollution stock that adversely affects Total Factor Productivity (TFP) in both green and brown firms. However, the effects of the pollution stock are not homogeneous across firms. Following Lamperti et al. (2019), climate damages are therefore modeled as heterogeneous stochastic shocks at the firm level. In each period, the aggregate pollution stock determines the probability that a firm is affected by a climate event, while the severity of the realized damage is drawn from a firm-specific probability distribution. The resulting shock reduces the current revenue and, consequently, the profit of the affected firm. This reduced-form specification captures heterogeneity in firms' exposure to physical climate risk and provides a channel through which climate damages affect firms' debt-servicing capacity and default risk and, ultimately, the financial stability of their lending banks.

In addition, following Annicchiarico et al. (2023), brown firms are subject to a proportional emissions tax and can reduce their emissions, and hence their associated tax burden, by adopting and progressively improving their abatement technology. Brown firms' decisions to adopt and further improve this technology depend primarily on the net marginal benefit of additional abatement.

In the interbank credit market, loan supply and demand are determined by a random fraction of the gap between outstanding non-financial corporate loans and banks' net worth. In each period, a bank may participate in the interbank market either as a lender or as a borrower. In-

[1] This decision rule applies in every period of the simulation except the first, in which firms are initially assigned to the brown or green type according to a binomial distribution.

terbank lenders (IB-lenders) may extend loans to multiple interbank borrowers (IB-borrowers), while the latter may seek funding from multiple lenders. The matching process between interbank borrowers and lenders is not purely random. Rather, IB-borrowers preferentially seek funding from IB-lenders offering the most favorable borrowing conditions, that is, the lowest interbank interest rates.

The evolution of the credit network is jointly determined by banks' credit supply and the credit demand of both firms and banks, which, in turn, depend on their respective leverage decisions. In addition, banks compute the RWA associated with their brown and green non-financial corporate exposures, as well as their interbank exposures, under both the standardized approach and the IRB approach. The introduction of the output floor affects the calculation of banks' RWA and, consequently, their regulatory capital requirements and solvency positions.

In addition to the output floor mechanism introduced by Roussel (2025), we incorporate two key features into the assessment of the policy. First, we introduce a feedback effect of the output floor on the target leverage adjustments of surviving banks. This mechanism allows the increase in RWA induced by the output floor to affect banks' leverage decisions and, in turn, their credit supply. It thereby provides a more consistent transmission of the output floor to both the volume and the cost of bank lending. Second, we introduce a brown output floor, whereby the floor constraint is applied specifically to the IRB risk weights associated with brown non-financial corporate exposures.

The remainder of this section provides further details on the methodological contributions. Unless otherwise specified, the other features of the model follow Roussel (2025).

3.1 Environmental features of the real sector

3.1.1 Firms' decisions of being green

In the first period, each firm n is assigned to either the brown ($n = n_b$) or green ($n = n_g$) type according to a binomial distribution. In subsequent periods (i.e., $t > 1$), each newly entering firm $\tilde{n} \in N$ chooses whether to operate as a brown or green firm based on the relative profitability and failure rates of surviving brown and green firms in the previous period. Accordingly, the probability that a new firm becomes brown is specified by the following logistic function:

$$P(\tilde{n} = n_b) = \frac{sb}{sb + (1 - sb)\exp\left[\lambda_{\tilde{n}}^{\Pi^f} \widehat{\Pi_{b,g,t-1}^{f,K}} + \lambda_{\tilde{n}}^{deff} def_{b,g,t-1}^{f}\right]} \tag{1}$$

where $\widehat{\Pi_{b,g,t-1}^{f,K}} = med\left(\frac{\Pi_{n_g,t-1}^{f}}{K_{n_g,t-1}}\right) - med\left(\frac{\Pi_{n_b,t-1}^{f}}{K_{n_b,t-1}}\right)$ denotes the difference in median profit rates between surviving green and brown firms in the previous period.[2] The term $def_{b,g,t-1}^{f} = def_{n_b,t-1}^{f} - def_{n_g,t-1}^{f}$ denotes the difference in default rates between brown and green firms in the previous period, with $def_{n_b,t-1}^{f} =$ Number of defaulting brown firms/Number of brown firms and $def_{n_g,t-1}^{f} =$ Number of defaulting green firms/Number of green firms. The coefficients $\lambda_{\tilde{n}}^{\Pi^f}$ and $\lambda_{\tilde{n}}^{deff}$ capture the sensitivity of new firms' production technology choices to differences in profitability and default rates between surviving brown and green firms, respectively. Finally, sb denotes the initial share of brown firms prior to the first period of the simulation.

Hence, equation (1) implies that a new firm is less likely to adopt a green production technology when surviving brown firms are more profitable than their green counterparts and when brown firms exhibit a lower default rate relative to green firms. These two components on the right-hand side of equation (1) capture two distinct dimensions underlying the choice of production technology: an extensive-margin risk, reflected in the relative default rates of brown and green firms, and an intensive-margin risk, captured by their relative profitability. Accordingly, new firms are more likely to adopt a brown production technology when brown firms exhibit both higher profitability and a lower incidence of default relative to green firms.

3.1.2 Brown firms decision of greening the production

In the first period, if firm n operates as a brown firm ($n = n_b$), it is subject to an emissions tax τ^{emiss} proportional to its emissions. Following Annicchiarico et al. (2023), emissions at the brown firm level are assumed to depend linearly on output:

$$Emiss_{n_b,t} = \phi^{emiss} Y_{n_b,t}, \tag{2}$$

[2] The profit rate is defined as profits relative to physical capital.

where ϕ^{emiss} is an emissions-intensity parameter that converts units of output into the corresponding volume of emissions (measured in Mt of CO_2). Accordingly, the emissions tax paid by a brown firm is given by:

$$TAX_{n_b,t}^{Emiss} = \tau^{emiss} Emiss_{n_b,t}. \tag{3}$$

In subsequent periods, a surviving brown firm n_b may adopt an abatement technology with intensity $\vartheta_{n_b,t}$ to reduce its emissions. Abatement is, however, costly for the firm. Following a standard convex specification, the abatement cost is quadratic in abatement intensity and proportional to the firm's output:

$$Abat_{n_b,t}^{cost} = \frac{\kappa^{abat}}{2} \vartheta_{n_b,t}^2 Y_{n_b,t}, \tag{4}$$

where $\kappa^{abat} > 0$ governs the marginal cost of abatement.

If a brown firm adopts the abatement technology, its emissions are reduced as a function of the intensity of abatement according to:

$$Emiss_{n_b,t}^{abat} = \frac{\phi^{emiss} Y_{n_b,t}}{1 + \vartheta_{n_b,t}}. \tag{5}$$

Hence, a higher abatement intensity $\vartheta_{n_b,t}$ reduces the emissions generated per unit of output. As a result, the emissions tax paid by the brown firm is reduced accordingly:

$$TAX_{n_b,t}^{Emiss-abat} = \tau^{emiss} Emiss_{n_b,t}^{abat} = \tau^{emiss} \frac{Emiss_{n_b,t}}{1 + \vartheta_{n_b,t}}. \tag{6}$$

At the beginning of each period $t > 1$, a surviving brown firm decides whether to increase its abatement intensity based on both firm-specific and aggregate market conditions. The firm-specific incentive is captured by the net marginal gain from increasing abatement intensity, which compares the marginal reduction in the emissions tax with the marginal cost of additional abatement. Based on equations (4), (5), and (6), this net marginal gain, evaluated using information from the previous period, is defined as:

$$NG_{n_b,t-1} = \frac{\tau^{emiss}\phi^{emiss}}{\left(1+\vartheta_{n_b,t-1}\right)^2} - \kappa^{abat}\vartheta_{n_b,t-1}. \tag{7}$$

The first term, $\frac{\tau^{emiss}\phi^{emiss}}{\left(1+\vartheta_{n_b,t-1}\right)^2}$, captures the marginal tax saving associated with a higher abatement intensity, whereas the second term, $\kappa^{abat}\vartheta_{n_b,t-1}$, represents its marginal abatement cost. A positive value of $NG_{n_b,t-1}$ therefore indicates that the marginal benefit of further abatement exceeds its marginal cost.

The probability that a surviving brown firm increases its abatement intensity is then specified by the following logistic function:

$$P\left(\vartheta_{n_b,t} > \vartheta_{n_b,t-1}\right) = \frac{\varrho}{\varrho + (1-\varrho)\exp\left[-\left(\lambda_{n_b}^{NG} NG_{n_b,t-1} + \lambda_{n_b}^{\Pi^f}\widehat{\Pi_{b,g,t-1}^{f,K}} + \lambda_{n_b}^{deff} def f_{b,g,t-1}^{f}\right)\right]}. \tag{8}$$

The coefficient $\lambda_{n_b}^{NG}$ governs the sensitivity of the abatement decision to the net marginal gain from increasing abatement intensity.

As in the production technology choice of newly entering firms, the abatement decision of surviving brown firms is also influenced by differences in profitability and default rates between surviving brown and green firms in the previous period. Accordingly, $\widehat{\Pi_{b,g,t-1}^{f,K}}$ and $def f_{b,g,t-1}^{f}$ capture market-level conditions affecting the incentive to increase abatement intensity, whereas $NG_{n_b,t-1}$ captures the firm-specific economic incentive associated with the marginal benefits and costs of additional abatement.

Finally, the parameter $\varrho \in (0,1)$ determines the baseline probability of increasing abatement intensity. In particular, when the firm-specific and market-level components entering the logistic function are equal to zero, the probability of increasing abatement intensity is equal to ϱ.

3.1.3 Climate features

Following Riccetti et al. (2013) and Catullo et al. (2021), each firm n uses physical capital $K_{n,t}$ to produce output $Y_{n,t}$ according to the following production function:

$$Y_{n,t} = \phi K_{n,t}^{\beta}, \tag{9}$$

where β denotes the output elasticity with respect to physical capital, while ϕ is a scale parameter governing firm productivity.

Each firm n finances its physical capital $K_{n,t}$ through its own net worth $E_{n,t}$ and bank loans $L_{n,t}^{f}$. The firm's balance-sheet identity is therefore given by:

$$K_{n,t} = E_{n,t} + L_{n,t}^{f}. \tag{10}$$

Furthermore, in line with Ferrari and Nispi-Landi (2024) and Roussel (2024b), we assume that only brown firms generate emissions, which contribute to the accumulation of an aggregate pollution stock that adversely affects the productive capacity of both green and brown firms through heterogeneous climate damages. Following Lamperti et al. (2019), these damages are modeled as idiosyncratic stochastic shocks at the firm level:

$$clim_{n,t} = \mathbb{I}_{n,t}\left(P\left(Pol_t\right)\right) Severity_{n,t}, \tag{11}$$

where $\mathbb{I}_{n,t}\left(P\left(Pol_t\right)\right)$ is a dummy variable capturing the occurrence of an idiosyncratic climate shock, drawn from a Bernoulli distribution with probability $P\left(Pol_t\right)$. Conditional on the occurrence of a climate shock, $Severity_{n,t}$ captures its severity and is drawn from a Beta distribution $\mathcal{B}(a_{pol}, b_{pol})$. Hence, the aggregate pollution stock affects firms through the probability of experiencing a climate shock, while the occurrence and severity of the realized damage are heterogeneous across firms.

The dynamics of the aggregate pollution stock are driven by emissions generated by brown firms. In line with Heutel (2012), Gibson and Heutel (2020), and Ferrari and Nispi-Landi (2024), the pollution stock evolves according to domestic emissions $Emiss_t$ and exogenous emissions from the rest of the world $Emiss_{RoW}$:

$$Pol_t = (1 - \delta^{pol}) Pol_{t-1} + \zeta^{pol}\left(Emiss_t + Emiss_{RoW}\right), \tag{12}$$

where ζ^{pol} is a physical conversion factor that converts CO_2 emissions into their carbon equivalent, the latter being used to construct the pollution stock (Jondeau et al., 2023). The parameter δ^{pol} denotes the natural decay rate of the pollution stock. While emissions from the rest of the world are assumed to be exogenous, aggregate domestic emissions are endogenously determined by the emissions generated by brown firms:

$$Emiss_t = \sum_{n_b=1}^{N_{b,t}} Emiss_{n_b,t}^{abat}, \tag{13}$$

where $N_{b,t}$ denotes the number of brown firms operating in period t.

As mentioned above, the accumulation of the pollution stock increases firms' exposure to idiosyncratic climate shocks. As specified in equation (11), the occurrence of such a shock is governed by the probability $P(Pol_t)$, which depends on the contemporaneous pollution stock and is defined as:

$$P(Pol_t) = 1 - \exp\left[-\lambda^{pol}\left(\frac{Pol_t}{Pol_0}\right)^{\nu^{pol}}\right], \tag{14}$$

where Pol_0 denotes the initial pollution stock prior to the first period of the simulation. The parameter $\lambda^{pol} > 0$ governs the overall sensitivity of climate-shock probability to the pollution stock, while $\nu^{pol} > 0$ determines the curvature of this relationship. In particular, for $\nu^{pol} > 1$, the pollution component entering the exponential hazard function increases more than proportionally with the pollution stock. Hence, a higher pollution stock raises the probability that firms are exposed to an idiosyncratic climate shock.

Following the realization of the climate shock, the effective output of each firm n, denoted by $\tilde{Y}_{n,t}$, corresponds to potential output adjusted for the realized climate damage:

$$\tilde{Y}_{n,t} = (1 - clim_{n,t})\phi K_{n,t}^{\beta}. \tag{15}$$

Accordingly, after the realization of the climate shock, the profit of firm n is given by:

$$\Pi_{n,t}^{f} = p_{n,t}^{f}\tilde{Y}_{n,t} - \sum_{m\in\Theta_{M_n}}^{M_n} r_{m,n,t}^{f} L_{n,m,t}^{f} - \mathbb{I}_{n_b,t}\left(TAX_{n,t}^{Emiss-abat} + Abat_{n,t}^{cost}\right), \tag{16}$$

where $p^f_{n,t}$ represents the stochastic net return per unit of effective output. This return is defined net of production costs, excluding financial costs, and is drawn from a normal distribution, $p^f_{n,t} \sim \mathcal{N}(\alpha, varp)$. The term $L^f_{n,m,t}$ denotes the amount of non-financial corporate loans granted to firm n by bank m, while $r^f_{m,n,t}$ denotes the corresponding lending rate. Finally, M_n denotes the number of banks lending to firm n in period t, with Θ_{M_n} representing the corresponding set of lending banks. The indicator $\mathbb{I}_{n_b,t}$ is equal to one if firm n operates as a brown firm and zero otherwise, ensuring that emissions taxes and abatement costs apply exclusively to brown firms.

3.2 Standard and brown output floor set-up in the banking sector

3.2.1 The output floor channel in leverage adjustment

In addition to the banking mechanisms governing the credit network in Roussel (2025), we introduce an additional channel through which the standard and brown output floors affect banks' leverage strategies.

From the second period onward, each surviving bank adjusts its target core leverage ratio according to both its profits realized in the previous period, $\Pi^b_{m,t-1}$, and the increase in RWA induced by the output floor. More specifically, the target core leverage ratio evolves according to:

$$\text{Lev}^{core}_{m,t} = \begin{cases} \text{Lev}^{core}_{m,t-1}\left(1 - \text{adj}^{lev}_b U(0,1)\right) + \kappa^{Lev}\text{Lev}^{core}_{m,t-1}\left(\dfrac{RWA^{Reg}_{m,t-1}}{RWA^{No\,Reg}_{m,t-1}} - 1\right), & \text{if } \Pi^b_{m,t-1} > 0, \\ \text{Lev}^{core}_{m,t-1}\left(1 + \text{adj}^{lev}_b U(0,1)\right) + \kappa^{Lev}\text{Lev}^{core}_{m,t-1}\left(\dfrac{RWA^{Reg}_{m,t-1}}{RWA^{No\,Reg}_{m,t-1}} - 1\right), & \text{otherwise.} \end{cases} \tag{17}$$

where $RWA^{Reg}_{m,t-1}$ denotes the regulatory RWA of bank m when either the standard or the brown output floor is implemented, whereas $RWA^{No\,Reg}_{m,t-1}$ denotes the corresponding RWA in the absence of an output floor. The parameter $\kappa^{Lev} \geq 0$ governs the sensitivity of the bank's target core leverage ratio to the relative increase in RWA induced by the output floor. Hence, whenever the output floor raises regulatory RWA relative to the no-output-floor benchmark, the feedback term is positive, leading the bank to increase its target core leverage ratio.

The rationale for introducing this output-floor feedback into equation (17) is consistent with empirical evidence showing that banks actively manage their capital positions around internal capital targets above minimum regulatory requirements (Memmel and Raupach, 2010). In the model, an increase in RWA induced by the output floor raises the capital-to-loans ratio that would be required to preserve the bank's pre-floor Capital Adequacy Ratio (CAR), thereby defining an output-floor-adjusted shadow target.[3] Banks are assumed to adjust only gradually toward this higher target, reflecting the fact that strengthening capital positions through retained earnings or new equity issuance, as well as restructuring lending portfolios, is costly and cannot generally be achieved within a single period. This partial-adjustment mechanism provides a more consistent transmission of the output floor to bank lending capacity and, through endogenous balance-sheet adjustments and credit-market matching, to lending volumes and conditions.

3.2.2 Banks profit and capital requirements

Banks compute their profits sequentially after all transactions in the non-financial corporate and interbank credit markets have been completed. First, each bank identifies defaults among the brown and green firms in its non-financial corporate loan portfolio. It then computes the corresponding non-performing non-financial corporate loans and deducts the associated credit losses from its net worth. In a second step, interbank lenders (IB-lenders) identify defaults among their interbank borrowers (IB-borrowers), compute the resulting non-performing interbank loans, and absorb the associated losses. In addition, each bank m collects deposits $D_{m,t}$, which are remunerated at the central bank rate r^{CB}. Banks may also hold a risk-free liquid asset $Liq_{m,t}$, remunerated at the same rate r^{CB}, whenever their target leverage position cannot be achieved solely through non-financial corporate and interbank lending.

[3] Let $L^{sup}_{m,t}$ denote the target lending capacity of bank m, and define its target capital-to-loans ratio as $Lev^{core}_{m,t} = E_{m,t}/L^{sup}_{m,t}$. In the absence of an output floor, the bank's CAR can be written as $CAR^{No\,Reg}_{m,t} = \frac{E_{m,t}}{RWA^{No\,Reg}_{m,t}} = Lev^{core}_{m,t} \frac{L^{sup}_{m,t}}{RWA^{No\,Reg}_{m,t}}$. Under the standard or brown output floor, the corresponding ratio is $CAR^{Reg}_{m,t} = \widehat{Lev}^{core}_{m,t} \frac{L^{sup}_{m,t}}{RWA^{Reg}_{m,t}}$. For a given target lending portfolio, preserving the pre-floor CAR, i.e., imposing $CAR^{Reg}_{m,t} = CAR^{No\,Reg}_{m,t}$, yields the output-floor-adjusted shadow target $\widehat{Lev}^{core}_{m,t} = Lev^{core}_{m,t} \frac{RWA^{Reg}_{m,t}}{RWA^{No\,Reg}_{m,t}}$. The model assumes that banks adjust only partially toward this shadow target.

Accordingly, bank profits differ depending on whether the bank acts as an IB-lender or an IB-borrower. For an IB-lender, profits are given by:

$$\begin{aligned}\Pi^b_{m,t} = &\sum_{n_b \in \Theta_{N_{b,m}}}^{N_{b,m}} r^f_{m,n_b,t} \widehat{L^f_{m,n_b,t}} + \sum_{n_g \in \Theta_{N_{g,m}}}^{N_{g,m}} r^f_{m,n_g,t} \widehat{L^f_{m,n_g,t}} \\ &+ \sum_{m' \in \Theta_{M'_m}}^{M'_m} r^{IB}_{m,m',t} \widehat{IB_{m,m',t}} + r^{CB} Liq^{IB\text{-}sup}_{m,t} - r^{CB} D_{m,t} - cE_{m,t-1}.\end{aligned} \tag{18}$$

For an IB-borrower, profits are given by:

$$\begin{aligned}\Pi^b_{m,t} = &\sum_{n_b \in \Theta_{N_{b,m}}}^{N_{b,m}} r^f_{m,n_b,t} \widehat{L^f_{m,n_b,t}} + \sum_{n_g \in \Theta_{N_{g,m}}}^{N_{g,m}} r^f_{m,n_g,t} \widehat{L^f_{m,n_g,t}} + r^{CB} Liq^{IB\text{-}dem}_{m,t} \\ &- \sum_{m \in \Theta_{M_{m'}}}^{M_{m'}} r^{IB}_{m,m',t} \widehat{IB_{m,m',t}} - r^{CB} D_{m,t} - cE_{m,t-1}.\end{aligned} \tag{19}$$

The terms $\widehat{L^f_{m,n_b,t}}$ and $\widehat{L^f_{m,n_g,t}}$ denote the performing brown and green non-financial corporate loans held by bank m, respectively, while $\widehat{IB_{m,m',t}}$ denotes performing interbank loans.[4] The terms $r^f_{m,n_b,t}$ and $r^f_{m,n_g,t}$ denote the lending rates charged on brown and green non-financial corporate loans, respectively, while $r^{IB}_{m,m',t}$ denotes the corresponding interbank lending rate.

In addition, each bank incurs an operating cost proportional to its beginning-of-period net worth, given by $cE_{m,t-1}$. The parameter c is indexed to the central bank rate such that, in the absence of non-financial corporate and interbank lending activity, banks do not generate positive profits.

Moreover, banks retain only a fraction $1 - \rho^b$ of their profits to increase their net worth, while the remaining fraction ρ^b is distributed through taxes and dividends. Accordingly, the pre-regulatory net worth of bank m, denoted by $\overline{E}_{m,t}$, evolves according to retained earnings and credit losses arising from non-performing brown and green non-financial corporate loans

[4] $\Theta_{N_{b,m}}$ and $\Theta_{N_{g,m}}$ denote the sets of brown and green firms, respectively, having a lending relationship with bank m. Moreover, $\Theta_{M_{m'}}$ denotes the set of IB-lenders providing interbank funding to IB-borrower m', whereas $\Theta_{M'_m}$ denotes the set of IB-borrowers receiving interbank funding from IB-lender m.

and interbank loans, denoted by $bad^{f,b}_{m,t}$, $bad^{f,g}_{m,t}$, and $bad^{IB}_{m,t}$, respectively:

$$\Delta\overline{E}_{m,t} \equiv \overline{E}_{m,t} - E_{m,t-1} = \begin{cases} (1-\rho^b)\Pi^b_{m,t} - bad^{f,b}_{m,t} - bad^{f,g}_{m,t} - bad^{IB}_{m,t}, & \text{if bank } m \text{ is an IB-lender,} \\ (1-\rho^b)\Pi^b_{m,t} - bad^{f,b}_{m,t} - bad^{f,g}_{m,t}, & \text{otherwise.} \end{cases} \tag{20}$$

The variable $\overline{E}_{m,t}$ therefore denotes the bank's net worth before the application of the regulatory capital constraint. Bank m defaults whenever $\overline{E}_{m,t} \leq 0$, that is, when retained earnings are insufficient to absorb the credit losses arising from its lending activities.

Furthermore, banks are subject to regulatory capital requirements. In the model, these requirements are represented by an additional prudential adjustment to the net-worth accumulation process. This adjustment depends on the deviation of the bank's capital adequacy ratio, $CAR_{m,t}$, from the minimum regulatory requirement ν. Specifically, the prudential adjustment applies to surviving banks (i.e., $\overline{E}_{m,t} > 0$) whose capital adequacy ratio falls below the regulatory threshold. The end-of-period net worth of bank m is therefore given by:

$$E_{m,t} = \begin{cases} \overline{E}_{m,t}\left[1 + \omega\left(CAR_{m,t} - \nu\right)\right], & \text{if } \overline{E}_{m,t} > 0 \text{ and } CAR_{m,t} < \nu, \\ \overline{E}_{m,t}, & \text{otherwise,} \end{cases} \tag{21}$$

where $\omega \geq 0$ governs the intensity of the prudential adjustment associated with a regulatory capital shortfall. The capital adequacy ratio of bank m is defined as the ratio of its beginning-of-period net worth to its regulatory risk-weighted assets:

$$CAR_{m,t} = \frac{E_{m,t-1}}{RWA_{m,t}}. \tag{22}$$

Because the model distinguishes between brown and green non-financial corporate exposures and interbank exposures, banks' RWA are computed as the sum of their credit exposures weighted by their respective risk weights, denoted by $Risk^{f}_{m,n_b,t}$, $Risk^{f}_{m,n_g,t}$, and $Risk^{IB}_{m,m',t}$, respectively.[5]

[5]Risk-free liquid assets carry a zero risk weight and are therefore excluded from the calculation of RWA.

For an IB-lender, RWA are given by:

$$\begin{aligned} RWA_{m,t} = & \sum_{n_b \in \Theta_{N_{b,m}}}^{N_{b,m}} Risk^{f}_{m,n_b,t} L^{f}_{m,n_b,t} + \sum_{n_g \in \Theta_{N_{g,m}}}^{N_{g,m}} Risk^{f}_{m,n_g,t} L^{f}_{m,n_g,t} \\ & + \sum_{m' \in \Theta_{M'_m}}^{M'_m} Risk^{IB}_{m,m',t} IB_{m,m',t}. \end{aligned} \tag{23}$$

For an IB-borrower, which does not hold interbank lending exposures on its asset side, RWA are given by:

$$RWA_{m,t} = \sum_{n_b \in \Theta_{N_{b,m}}}^{N_{b,m}} Risk^{f}_{m,n_b,t} L^{f}_{m,n_b,t} + \sum_{n_g \in \Theta_{N_{g,m}}}^{N_{g,m}} Risk^{f}_{m,n_g,t} L^{f}_{m,n_g,t}. \tag{24}$$

In addition to the prudential adjustment described above, banks are subject to a minimum solvency threshold η, with $\eta < \nu$. If the capital adequacy ratio of bank m falls below this threshold, i.e., $CAR_{m,t} < \eta$, the bank is deemed insolvent by the regulatory authority and is forced to exit the market.

3.2.3 Implementation of the standard and brown output floor

In the framework of Roussel (2025), the RWA associated with non-financial corporate and interbank exposures can be computed under either the IRB or the standardized approach. In the model, the specification of the IRB approach closely follows the credit-risk framework defined under Basel III, whereas the standardized approach relies on a mapping of external credit ratings into regulatory risk weights. At each period, bank m selects a single credit-risk approach—either the standardized or the IRB approach—for its entire non-financial corporate loan portfolio, irrespective of whether the underlying exposures are brown or green. The approach selected for non-financial corporate exposures may, however, differ from that applied to interbank exposures. For each asset class, the probability that bank m adopts the IRB approach depends on its size, proxied by its net worth.

Once RWA have been computed under both approaches, the output floor is applied to banks using the IRB approach. Under the standard output floor, the regulatory RWA of bank m in period t are given by:

$$RWA_{m,t}^{OF} = \Gamma\left(P\left(IRB_{m,t}\right)\right)\max\left\{RWA_{m,t}^{IRB}\,;\,0.725 * RWA_{m,t}^{SA}\right\}+\left[1-\Gamma\left(P\left(IRB_{m,t}\right)\right)\right]RWA_{m,t}^{SA}, \tag{25}$$

where $\Gamma\left(P\left(IRB_{m,t}\right)\right)$ is an dummy variable equal to one when bank m adopts the IRB approach in period t, and zero otherwise. Hence, for IRB banks, regulatory RWA are bounded from below at 72.5% of the RWA that would result from the standardized approach, whereas banks using the standardized approach remain unaffected by the output floor.

The RWA computed under the IRB and standardized approach depend on the bank's position in the non-financial corporate and interbank market. For an IB-lender, they are respectively given by:

$$\begin{aligned} RWA_{m,t}^{IRB} = & \sum_{n_b \in \Theta_{N_{b,m}}}^{N_{b,m}} RW_{m,n_b,t}^{IRB} L_{m,n_b,t}^{f} + \sum_{n_g \in \Theta_{N_{g,m}}}^{N_{g,m}} RW_{m,n_g,t}^{IRB} L_{m,n_g,t}^{f} \\ & + \sum_{m' \in \Theta_{M'_m}}^{M'_m} RW_{m,m',t}^{IRB} IB_{m,m',t}, \end{aligned} \tag{26}$$

$$\begin{aligned} RWA_{m,t}^{SA} = & \sum_{n_b \in \Theta_{N_{b,m}}}^{N_{b,m}} RW_{m,n_b,t}^{SA} L_{m,n_b,t}^{f} + \sum_{n_g \in \Theta_{N_{g,m}}}^{N_{g,m}} RW_{m,n_g,t}^{SA} L_{m,n_g,t}^{f} \\ & + \sum_{m' \in \Theta_{M'_m}}^{M'_m} RW_{m,m',t}^{SA} IB_{m,m',t}. \end{aligned} \tag{27}$$

For an IB-borrower, which does not hold interbank lending exposures on its asset side, RWA are respectively given by:

$$RWA_{m,t}^{IRB} = \sum_{n_b \in \Theta_{N_{b,m}}}^{N_{b,m}} RW_{m,n_b,t}^{IRB} L_{m,n_b,t}^{f} + \sum_{n_g \in \Theta_{N_{g,m}}}^{N_{g,m}} RW_{m,n_g,t}^{IRB} L_{m,n_g,t}^{f}, \tag{28}$$

$$RWA_{m,t}^{SA} = \sum_{n_b \in \Theta_{N_{b,m}}}^{N_{b,m}} RW_{m,n_b,t}^{SA} L_{m,n_b,t}^{f} + \sum_{n_g \in \Theta_{N_{g,m}}}^{N_{g,m}} RW_{m,n_g,t}^{SA} L_{m,n_g,t}^{f}. \tag{29}$$

The terms $RW_{m,n_b,t}^{IRB}$, $RW_{m,n_g,t}^{IRB}$, and $RW_{m,m',t}^{IRB}$ denote the risk weights assigned under the IRB approach to brown non-financial corporate, non-financial green corporate, and interbank exposures, respectively. Similarly, $RW^{SA}_{m,n_b,t}$, $RW^{SA}_{m,n_g,t}$, and $RW^{SA}_{m,m',t}$ denote the corresponding risk weights under the standardized approach.

The risk-weight decomposition introduced above allows us to define the effective risk weights applied to non-financial corporate and interbank exposures as follows:

$$Risk^{f}_{m,n,t} = \Gamma\left(P\left(IRB_{m,t}\right)\right) RW^{IRB}_{m,n,t} + \left[1 - \Gamma\left(P\left(IRB_{m,t}\right)\right)\right] RW^{SA}_{m,n,t}, \tag{30}$$

$$Risk^{IB}_{m,m',t} = \Gamma\left(P\left(IRB_{m,t}\right)\right) RW^{IRB}_{m,m',t} + \left[1 - \Gamma\left(P\left(IRB_{m,t}\right)\right)\right] RW^{SA}_{m,m',t}. \tag{31}$$

Hence, the effective risk weight corresponds to the IRB risk weight when bank m adopts the IRB approach and to the SA risk weight otherwise. For non-financial corporate exposures, this specification applies to both brown and green loans, i.e., $n \in \{n_b, n_g\}$.

Finally, we introduce a brown output floor, which restricts the application of the output floor to brown non-financial corporate and interbank exposures, while green non-financial corporate exposures remain subject to their unconstrained IRB risk weights. Accordingly, the regulatory RWA of bank m under the brown output floor are given by:

$$\begin{aligned} RWA^{BOF}_{m,t} = \Gamma\left(P\left(IRB_{m,t}\right)\right) \max &\left\{ \left(RWA^{IRB}_{m,t} - \sum_{n_g \in \Theta_{N_{g,m}}}^{N_{g,m}} RW^{IRB}_{m,n_g,t} L^{f}_{m,n_g,t} \right); \right. \\ &\left. 0.725 \left(RWA^{SA}_{m,t} - \sum_{n_g \in \Theta_{N_{g,m}}}^{N_{g,m}} RW^{SA}_{m,n_g,t} L^{f}_{m,n_g,t} \right) \right\} \\ &+ \Gamma\left(P\left(IRB_{m,t}\right)\right) \sum_{n_g \in \Theta_{N_{g,m}}}^{N_{g,m}} RW^{IRB}_{m,n_g,t} L^{f}_{m,n_g,t} \\ &+ \left[1 - \Gamma\left(P\left(IRB_{m,t}\right)\right)\right] RWA^{SA}_{m,t}. \end{aligned} \tag{32}$$

Under this specification, the brown output floor generates two complementary transmission channels. First, it has an immediate regulatory effect: whenever the floor is binding, it raises the regulatory RWA of IRB banks and thereby reduces their capital adequacy ratio, potentially bringing them closer to the minimum regulatory capital requirement (see equation (21)). Second, it generates a dynamic behavioral response through banks' leverage management. By increasing RWA relative to the no-output-floor benchmark, the brown output floor induces affected banks to gradually raise their target capital-to-loans ratio in subsequent periods (see equation (17)). The interaction of these two channels allows the brown output floor to affect both banks' regulatory capital positions and their subsequent credit supply decisions.

3.3 Simulation: Timing of Events

The model evolves in discrete time. Within each period, agents' decisions and market interactions take place sequentially according to the following timing:

1. Defaulted banks and firms are replaced by new entrants endowed with initial net worth.

2. New firms decide whether to adopt a green or brown production technology, while surviving brown firms decide whether to improve their abatement technology.

3. Firms adjust their target leverage ratios according to their past profitability.

4. Based on their updated target leverage ratios, firms determine their demand for corporate loans.

5. Banks adjust their target core leverage ratios according to their past profitability and the output-floor constraint.

6. Based on their updated target core leverage ratios, banks determine their supply of corporate loans and the bank-specific component of the corporate lending rate.

7. Each firm selects χ banks in the corporate loan market and contracts loans with the selected banks, determining the amount and interest rate of each corporate loan.

8. Firms combine their net worth and corporate borrowing to finance the physical capital used in production.

9. Brown firms generate emissions as a by-product of production, net of the effect of their abatement technology, and pay the corresponding emissions tax. Aggregate emissions contribute to the accumulation of the pollution stock.

10. Idiosyncratic climate shocks are realized and affect firms' revenues and profitability.

11. Banks identify defaulted non-financial corporate borrowers, compute non-performing brown and green non-financial corporate loans, and determine the income generated by performing non-financial corporate loans.

12. Banks enter the interbank market either as interbank suppliers (IB-suppliers) or interbank borrowers (IB-borrowers).

13. IB-borrowers determine their liquidity positions and their demand for interbank loans.

14. IB-suppliers and IB-borrowers are matched and conduct transactions in the interbank loan market.

15. IB-borrowers determine their deposit positions.

16. IB-suppliers determine their liquidity and deposit positions.

17. IB-suppliers and IB-borrowers compute their RWA under the IRB or standardized approach, depending on the credit-risk methodology adopted by each bank.

18. When applicable, the standard or brown output floor is imposed on the relevant IRB-based RWA, thereby determining each bank's regulatory RWA.

19. Based on regulatory RWA, banks compute their capital adequacy ratios.

20. The prudential regulator assesses whether surviving IB-suppliers and IB-borrowers satisfy the minimum capital requirement. Banks that fail to meet this requirement are declared insolvent.

21. Defaulted banks and firms exit the market.

$\Rightarrow$ Once all these steps have been completed, the simulation proceeds to the next period.

4 Calibration and Empirical Validation

The simulated credit network consists of 500 firms and 50 banks. Each simulation runs for 1,000 annually periods, with the first 200 periods discarded as a burn-in phase. Most non-environmental parameters are calibrated following Roussel (2025), while the remaining parameters are calibrated through a moment-matching procedure based on empirical data for the euro area. Specifically, the targeted moments include the mean and standard deviation of the share of brown loans in total non-financial corporate lending, the mean and standard deviation of non-performing loan ratios for brown and green firms, the mean and standard deviation of banks' leverage ratios, and the average share of credit exposures evaluated under the IRB approach. Since the framework of Roussel (2025) generates stationary dynamics for output, emissions, and credit, we focus the calibration on the levels and cross-sectional composition of the credit network rather than targeting moments related to the growth dynamics of these aggregate variables. Table 4 and Table 5 in the Appendix report the calibrated values of the non-environmental and environmental parameters, respectively.

The empirical moments used in the calibration are primarily constructed from the EBA EU-wide Transparency Exercises, which provide harmonized bank-level information on credit exposures, asset quality, regulatory approaches, and capitalization for a large sample of European banks.[6] To distinguish between brown and green non-financial corporate exposures, we combine the sectoral breakdown of non-financial corporate lending reported by the EBA according to the NACE classification with the Climate Policy Relevant Sectors (CPRS) taxonomy.[7] Corporate exposures belonging to the selected CPRS categories are classified as brown, while the remaining exposures constitute the non-brown category, which corresponds to green firms in the model.

Particular attention is paid to the manufacturing sector (NACE C), which encompasses activities characterized by substantial heterogeneity in their environmental footprint. Rather than classifying the entire manufacturing sector as brown, we use the EBA environmental information reported under indicator K41 to identify the fraction of manufacturing exposures associated with environmentally sensitive activities. Only this fraction is allocated to the brown category, while the remaining manufacturing exposures are classified as non-brown. This approach

[6] The EBA EU-wide Transparency Exercise data are available at https://www.eba.europa.eu/risk-and-data-analysis/risk-analysis/eu-wide-transparency-exercise.

[7] Information on the NACE classification is available from Eurostat at https://ec.europa.eu/eurostat/web/nace. The CPRS classification and the corresponding NACE–CPRS mapping are available at https://www.df.uzh.ch/en/people/professor/battiston/projects/CPRS.html.

avoids mechanically treating all manufacturing activities as carbon-intensive and provides a more granular measure of banks' exposure to brown non-financial corporate lending.

Based on this classification, the brown credit share is computed as the ratio of brown non-financial corporate exposures to total non-financial corporate exposures. The same mapping is applied to non-performing exposures to construct separate asset-quality indicators for the two categories: brown and green non-performing loan ratios are calculated as non-performing exposures in each category relative to the corresponding amount of non-financial corporate credit. The remaining calibration targets are directly derived from the EBA EU-wide Transparency Exercises. The bank leverage ratio captures banks' capitalization, while the share of IRB credit measures the proportion of relevant credit exposures evaluated under the Internal Ratings-Based approach. For each variable, the empirical moments are obtained by pooling the available bank-level observations over the sample period and computing the corresponding mean and, where relevant, standard deviation.

Table 1 compares the empirical moments for the euro area with their simulated counterparts. Overall, the calibrated model provides a satisfactory replication of the targeted empirical averages. The simulated share of brown credit amounts to 51.22%, compared with 55.75% in the data. The model also closely reproduces the average non-performing loan ratios across firm types, with simulated values of 4.18% and 3.99% for brown and green firms, respectively, compared with empirical values of 4.03% and 3.92%. Importantly, the model reproduces the empirical ranking of credit risk across firm types, as brown firms exhibit a slightly higher non-performing loan ratio than green firms. The simulated share of credit exposures evaluated under the IRB approach (53.28%) is also close to its empirical counterpart (51.4%).

Furthermore, the model generates an average leverage ratio of 6.11%, which is lower than its empirical value equal to 8.61%. Moreover, the simulated cross-sectional dispersion is higher than its empirical counterpart for the brown credit share and both brown and green non-performing loan ratios, whereas the dispersion of banks' leverage ratios is slightly lower in the simulations. These differences suggest that the model tends to generate greater heterogeneity in the composition and credit quality of non-financial corporate loan portfolios than observed in the data. Nevertheless, the close correspondence between most simulated and empirical av-

Table 1: Matching moments results

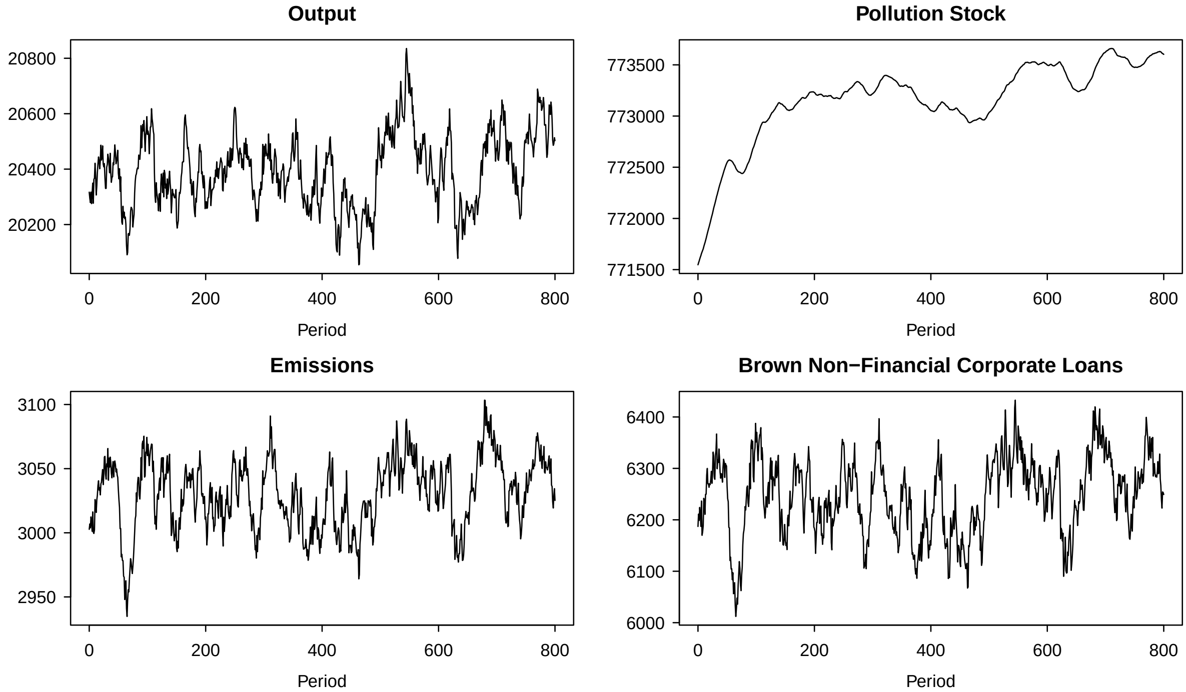
	Euro area data		Simulated data		Data source
	Average	Stand. Dev.	Average	Stand. Dev.	
Brown credit shares	0.55748	0.1874	0.5122	0.2946	EBA and CPRS/NACE
Brown non-performing loans	0.0403	0.0719	0.0418	0.1065	EBA and CPRS/NACE
Green non-performing loans	0.0392	0.0618	0.0399	0.1047	EBA and CPRS/NACE
Banks' leverage ratio	0.0861	0.0356	0.0611	0.0302	EBA
Share of IRB credits	0.514	–	0.5328	–	EBA

erages indicates that the calibrated model provides a reasonable quantitative representation of the main structural characteristics of the euro area credit network considered in the analysis.

Futhermore, Figure 1 and Figure 2 report the average dynamics of the main real, environmental, and credit variables across 100 Monte Carlo replications after the burn-in period. Overall, the simulations display stationary fluctuations around relatively stable long-run levels, without exhibiting persistent explosive or declining dynamics. Aggregate output fluctuates around a stable level, while brown and green non-financial corporate lending follow similar stationary patterns. Consequently, total non-financial corporate lending and total aggregate credit also remain broadly stable over the simulation horizon. Interbank lending exhibits comparatively higher short-run volatility, reflecting the role of the interbank market in accommodating banks' heterogeneous and time-varying funding needs. Taken together, these dynamics suggest that the endogenous interactions between firms and banks generate persistent fluctuations in credit allocation without destabilizing the aggregate credit network.

The environmental variables exhibit a slightly different pattern. While aggregate emissions fluctuate around a relatively stable level, the pollution stock initially increases before gradually converging toward a higher long-run level. This difference reflects the stock-flow structure of the environmental block: current emissions continuously add to the pollution stock, whereas the natural decay of accumulated pollution only partially offsets these additional emissions. The stabilization of the pollution stock therefore occurs once new emissions are approximately compensated by its natural decay. Importantly, the absence of a persistent upward trend in emissions, output, and brown lending indicates that the convergence of the pollution stock

Figure 1: Average dynamics of aggregate output, brown non-financial corporate loans, emissions and pollution stock.



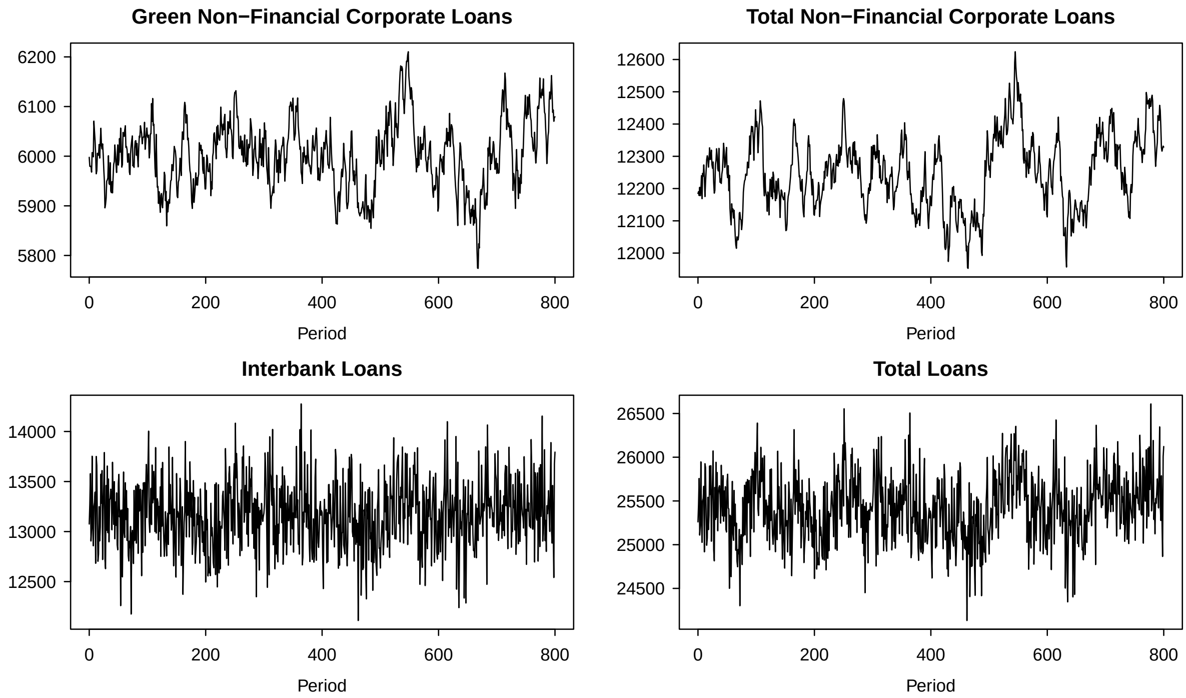
Notes: The figure plots average evolutions across Monte Carlo repetitions with different random seeds in each scenario.

does not result from a progressive contraction of economic or brown credit activity. Rather, it reflects the endogenous long-run balance between emissions and pollution decay generated by the environmental block of the model.

5 The distributional effects of the Brown Output Floor

We first investigate how the standard and brown output floors affect the cross-sectional distribution of banks' RWA density. Table 2 reports the first four moments of the RWA-density distribution, while Figure 3 illustrates the evolution of its mean and standard deviation across regulatory scenarios. When all banks are considered, average RWA density decreases by 1.290% under the standard output floor and by 1.576% under the brown output floor relative to the no-output-floor benchmark. This aggregate decline, however, masks opposite developments across regulatory approaches. Among IRB banks, which are directly targeted by the output-floor constraint, average RWA density increases significantly by 5.172% under the standard output floor and by

Figure 2: Average dynamics of green and total non-financial corporate loans, interbank loans and aggregate loans.



Notes: The figure plots average evolutions across Monte Carlo repetitions with different random seeds in each scenario.

3.561% under the brown output floor. By contrast, average RWA density among SA banks decreases significantly by 2.282% and 2.231%, respectively. Hence, the decline observed for the banking system as a whole is driven by the reduction among SA banks, which more than offsets the increase experienced by directly affected IRB banks. This decomposition highlights the distinction between the direct regulatory effect of the output floor on IRB banks and the endogenous adjustments that propagate throughout the credit network.

The standard deviation of RWA density provides further evidence on the prudential implications of the two regulatory designs. Among IRB banks, RWA-density dispersion decreases markedly relative to the no-output-floor benchmark, by 8.263% under the standard output floor and by 8.477% under the brown output floor. Importantly, the direct Brown-versus-Standard difference is small (-0.233%) and statistically insignificant ($p = 0.119$). Restricting the output floor to brown exposures therefore does not significantly alter its ability to reduce RWA-density dispersion among IRB banks. The conclusion is more nuanced for the banking system

Table 2: Changes in the RWA density distribution under the standard and brown output floors

Statistic	No output floor	Standard output floor			Brown output floor			Brown vs. Standard	
		Value	Variation	p-value	Value	Variation	p-value	Variation	p-value
RWA density – All banks									
Mean	0.347	0.342	-1.290%	< 0.001	0.341	-1.576%	< 0.001	-0.289%	< 0.001
Standard deviation	0.105	0.101	-4.084%	< 0.001	0.102	-3.427%	< 0.001	0.685%	< 0.001
Skewness	-0.114	-0.008	92.620%	< 0.001	0.010	108.422%	< 0.001	214.123%	< 0.001
Kurtosis	1.939	1.924	-0.786%	< 0.001	1.890	-2.576%	< 0.001	-1.804%	< 0.001
RWA density – IRB banks									
Mean	0.274	0.289	5.172%	< 0.001	0.284	3.561%	< 0.001	-1.532%	< 0.001
Standard deviation	0.080	0.073	-8.263%	< 0.001	0.073	-8.477%	< 0.001	-0.233%	0.118
Skewness	0.172	0.133	-22.782%	< 0.001	0.262	52.353%	< 0.001	97.301%	< 0.001
Kurtosis	2.922	2.758	-5.598%	< 0.001	2.863	-2.013%	< 0.001	3.798%	< 0.001
RWA density – SA banks									
Mean	0.374	0.366	-2.282%	< 0.001	0.366	-2.231%	< 0.001	0.051%	0.499
Standard deviation	0.100	0.102	1.901%	< 0.001	0.102	1.661%	< 0.001	-0.236%	0.0167
Skewness	-0.434	-0.354	18.509%	< 0.001	-0.358	17.622%	< 0.001	-1.088%	0.316
Kurtosis	2.144	2.045	-4.618%	< 0.001	2.051	-4.303%	< 0.001	0.330%	0.163

Notes: Each value represents the average across Monte Carlo simulations after the burn-in period. For each regulatory scenario, the variation relative to the no-output-floor scenario is measured as

$$\Delta X^s = 100 \times \frac{X^s - X^{\text{No OF}}}{X^{\text{No OF}}}, \qquad s \in \{\text{Standard}, \text{Brown}\}.$$

The Brown-versus-Standard variation is computed as

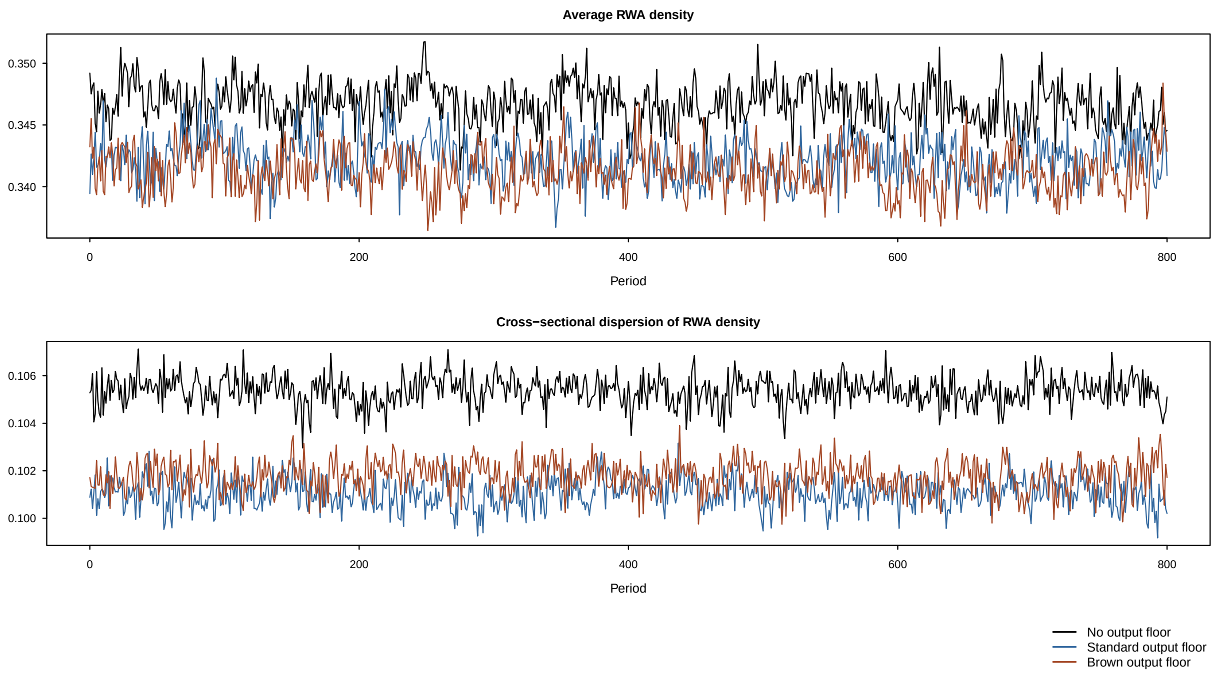
$$\Delta X^{B/S} = 100 \times \frac{X^{\text{Brown}} - X^{\text{Standard}}}{X^{\text{Standard}}}.$$

The reported two-sided p-values test the null hypothesis that the mean across Monte Carlo replications under the relevant scenarios is equal. For the Standard and Brown output-floor columns, each scenario is compared with the no-output-floor benchmark. For the Brown-versus-Standard columns, the null hypothesis is that the mean under the brown output floor is equal to that under the standard output floor. A p-value below 5% indicates a statistically significant difference at the 5% level. Values below 0.001 are reported as $p < 0.001$.

as a whole: the standard deviation decreases by 4.084% under the standard output floor and by 3.427% under the brown output floor, while the direct comparison shows a significantly higher dispersion under the latter ($+0.685\%$, $p < 0.001$). This aggregate difference appears to reflect a composition effect arising from the heterogeneous responses of IRB and SA banks. In particular, while both regulatory designs generate a statistically comparable reduction in RWA-density dispersion among IRB banks, the evolution of RWA density among SA banks, together with the opposite movements in average RWA density between IRB and SA banks, shapes the overall cross-sectional dispersion when both groups are considered jointly.

The full RWA-density distributions reported in Figure 4 complement these results by showing that both output-floor designs affect the shape of the distribution for IRB and SA banks

Figure 3: Evolution of the mean and cross-sectional dispersion of RWA density under alternative output-floor regimes.

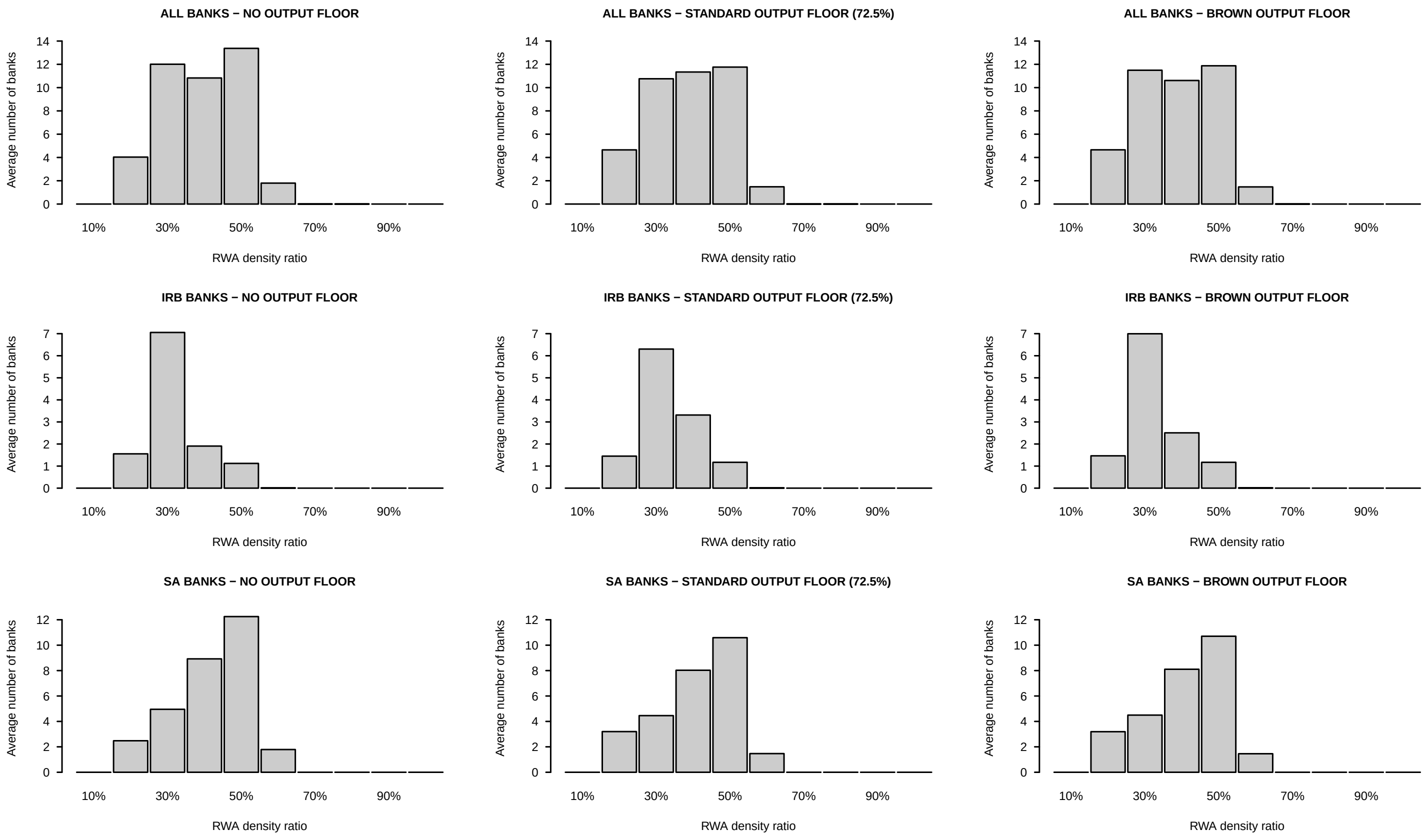


Notes: Bars represent the average number of banks per period and Monte Carlo repetition. RWA density excludes risk−free liquidity.

relative to the no-output-floor benchmark. This graphical evidence is consistent with Table 2, which indicates statistically significant changes in the first four moments of the RWA-density distribution for both types of banks. However, the distortion in the shape of the distribution appears more pronounced for IRB banks, which are directly targeted by the output-floor constraint, than for SA banks. In particular, the distributions of SA banks under the standard and brown output floors remain relatively similar to each other. This is confirmed by the direct Brown-versus-Standard tests, which indicate no statistically significant difference in the mean, standard deviation, skewness, or kurtosis of RWA density among SA banks. By contrast, among IRB banks, the choice between the standard and brown designs significantly affects the mean, skewness, and kurtosis of the distribution, although their effects on its standard deviation are statistically indistinguishable.

Hence, while both output floors propagate to SA banks through the endogenous adjustments of the banking network, the specific design of the regulatory floor matters primarily for the shape of the RWA-density distribution of directly affected IRB banks.

Figure 4: Impact of standard and brown output floors on RWA-density distributions.

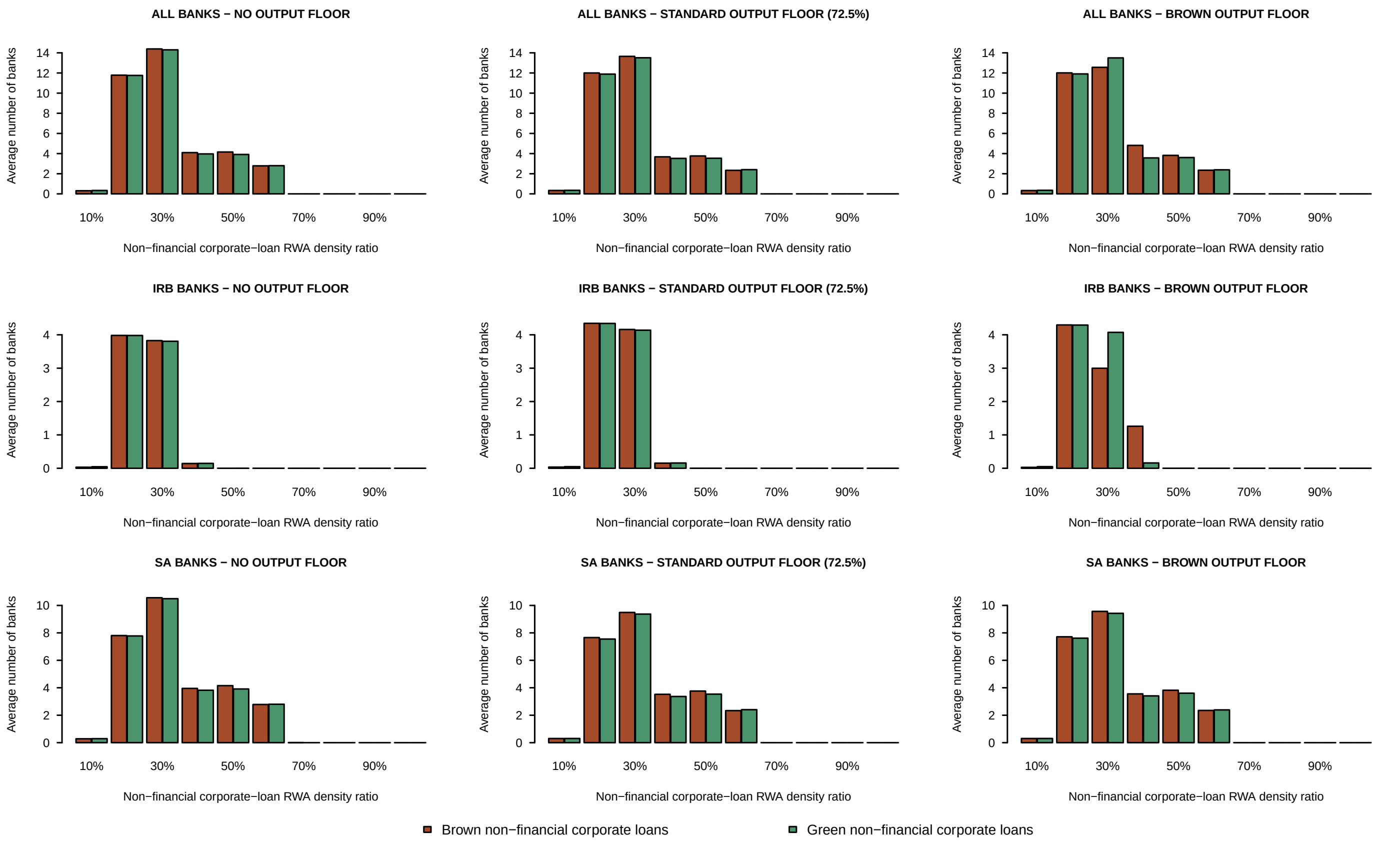


Notes: Bars represent the average number of banks per period and Monte Carlo repetition. RWA density excludes risk−free liquidity.

Finally, Figure 5 provides a more granular view of the mechanism underlying these distributional effects by distinguishing the RWA-density distributions associated with brown and green non-financial corporate exposures. The brown output floor particularly affects the distribution of brown non-financial corporate RWA density among IRB banks, which are directly subject to the regulatory constraint. In particular, the brown output floor reduces the frequency of IRB banks with brown non-financial corporate RWA densities in the 30–40% interval and increases the frequency of banks in the 40–50% interval. This rightward reallocation of part of the distribution is consistent with the intended mechanism of the brown output floor, which raises regulatory RWA whenever internally estimated RWA for brown exposures falls below 72.5% of the corresponding standardized-approach benchmark.

Importantly, however, this adjustment is selective rather than corresponding to a mechanical truncation of the lower tail of the distribution. Indeed, RWA-density classes below the 30–40%

Figure 5: Non-financial corporate-loan RWA-density distributions for brown and green firms across bank groups and output-floor regimes.



Notes: Bars represent the average number of banks per period and Monte Carlo repetition.
A bank may appear in both distributions when it holds both brown and green corporate exposures.

interval are comparatively less affected by the brown output floor. This pattern reflects the relative nature of the regulatory constraint: whether the brown output floor binds depends not on the absolute level of a bank's internally estimated brown RWA density, but on its position relative to the corresponding standardized-approach RWA. Consequently, banks displaying the lowest IRB RWA densities are not necessarily those for which the brown output floor is binding. The distributional adjustment therefore depends jointly on banks' internally estimated risk weights, their standardized-approach benchmarks, and the composition of their loan portfolios.

6 The macroeconomic, macrofinancial, and environmental impact of the Brown Output Floor

We next examine whether the distributional changes in regulatory risk documented above translate into aggregate macrofinancial, macroeconomic, and environmental effects. Table 3 and Figure 6 first show that both output-floor designs significantly affect banks' aggregate RWA. Average RWA increases by 1.137% under the standard output floor and by 0.798% under the brown output floor relative to the no-output-floor benchmark, while RWA dispersion increases by 14.004% and 12.877%, respectively.

Table 3: Effects of the standard and brown output floors on the main model outcomes

	No output	Standard output floor			Brown output floor			Brown vs. Standard	
Outcome	**floor**	**Value**	**Variation**	**p-value**	**Value**	**Variation**	**p-value**	**Variation**	**p-value**
Output	20,395.305	20,442.109	0.229%	0.100	20,435.906	0.199%	0.199	−0.030%	0.844
Emissions	3,030.132	3,041.241	0.367%	0.044	3,034.506	0.144%	0.454	−0.221%	0.276
Pollution stock	773,155.598	773,435.320	0.036%	0.011	773,265.226	0.014%	0.332	−0.022%	0.147
Brown non-financial corporate loans	6,246.150	6,273.581	0.439%	0.065	6,254.283	0.130%	0.604	−0.308%	0.250
Green non-financial corporate loans	6,002.222	6,008.350	0.102%	0.703	6,019.305	0.285%	0.308	0.182%	0.520
Total non-financial corporate loans	12,248.372	12,281.931	0.274%	0.162	12,273.588	0.206%	0.337	−0.068%	0.755
Interbank loans	13,173.035	12,468.806	−5.346%	< 0.001	12,479.582	−5.264%	< 0.001	0.086%	0.767
Total loans	25,421.407	24,750.736	−2.638%	< 0.001	24,753.170	−2.629%	< 0.001	0.010%	0.968
Mean RWA	118.854	120.205	1.137%	< 0.001	119.802	0.798%	0.001	−0.335%	0.176
RWA dispersion	234.795	267.675	14.004%	< 0.001	265.029	12.877%	< 0.001	−0.988%	< 0.001

Notes: Each value represents the average across Monte Carlo simulations after the burn-in period. For each regulatory scenario, the percentage variation relative to the no-output-floor scenario is calculated as

$$\Delta X^s = 100 \times \frac{X^s - X^{\text{No OF}}}{X^{\text{No OF}}}, \qquad s \in \{\text{Standard}, \text{Brown}\}.$$

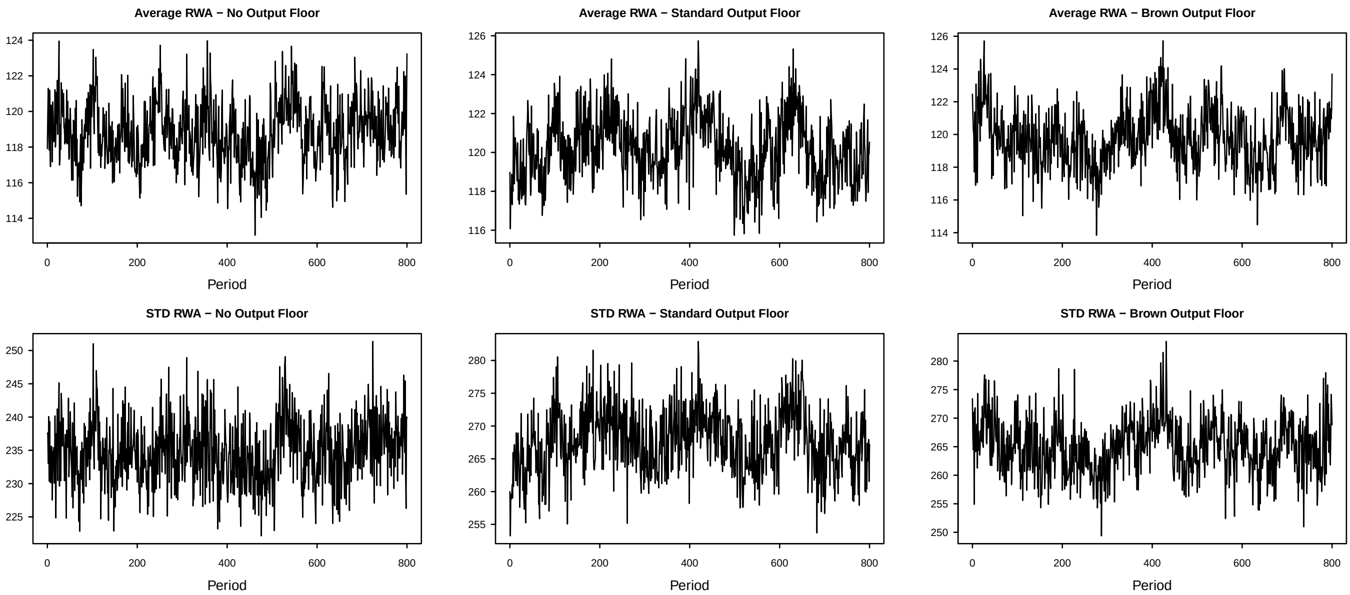
The percentage variation between the brown and standard output-floor scenarios is calculated as

$$\Delta X^{B/S} = 100 \times \frac{X^{\text{Brown}} - X^{\text{Standard}}}{X^{\text{Standard}}}.$$

The reported two-sided p-values test the null hypothesis that the mean across Monte Carlo replications under the relevant scenarios is equal. For the Standard and Brown output-floor columns, each regulatory scenario is compared with the no-output-floor benchmark. For the Brown-versus-Standard columns, the null hypothesis is that the mean under the brown output floor is equal to that under the standard output floor. A p-value below 5% indicates a statistically significant difference. Values below 0.001 are reported as $p < 0.001$.

The direct Brown-versus-Standard comparison indicates that the difference in average RWA is not statistically significant (-0.335%, $p = 0.176$), whereas RWA dispersion is significantly lower under the brown output floor (-0.988%, $p < 0.001$). Hence, although both policies increase the regulatory risk burden, targeting the floor at brown exposures produces a less

Figure 6: Evolution of the average and standard deviation of RWA under alternative output-floor regimes.



Notes: The figure plots average evolutions across Monte Carlo repetitions with different random seeds in each scenario.

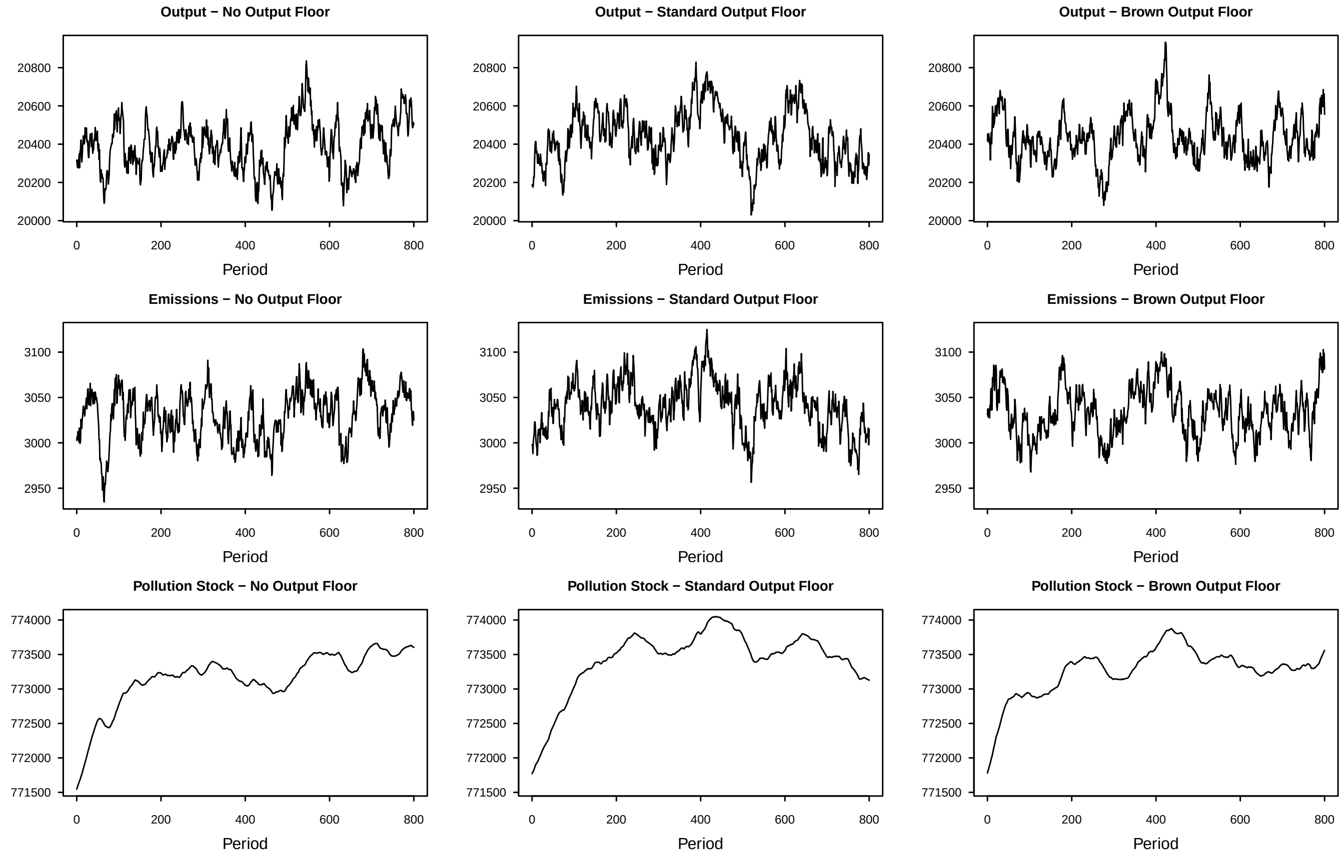
heterogeneous increase in the level of RWA across banks.

Despite this tightening of regulatory risk, neither output-floor design generates a significant contraction in lending to non-financial corporations. Total non-financial corporate lending changes only modestly under both policies and remains statistically indistinguishable from the no-output-floor benchmark. Its composition nevertheless reveals an interesting pattern. Under the standard output floor, brown non-financial corporate loans increase by 0.439%, an effect that is significant at the 10% level ($p = 0.065$), whereas green non-financial corporate lending remains statistically unchanged. Under the brown output floor, the increase in brown lending is considerably smaller ($+0.130\%$) and statistically insignificant ($p = 0.604$). However, the direct Brown-versus-Standard difference in brown lending is itself insignificant ($p = 0.250$), calling for a cautious interpretation. More generally, the balance-sheet adjustment occurs primarily through the interbank market: interbank lending falls by 5.346% under the standard output floor and by 5.264% under the brown output floor, causing total lending to decline by approximately 2.6% under both policies. Thus, the regulatory tightening primarily reshapes the composition of bank credit rather than generating a generalized contraction in the financing of the real sector.

The limited transmission to non-financial corporate lending is reflected in aggregate real activity. As shown in Figure 7 output remains close across the three regulatory scenarios throughout the simulation, consistently with the statistically insignificant average effects reported in Table 3. Environmental outcomes, however, reveal a difference relative to the no-output-floor benchmark. Under the standard output floor, emissions increase by 0.367% ($p = 0.044$) and the pollution stock by 0.036% ($p = 0.011$). Although quantitatively small, both effects are statistically significant. Under the brown output floor, the corresponding increases are smaller, at 0.144% and 0.014%, and statistically insignificant ($p = 0.454$ and $p = 0.332$, respectively). Together with the marginally significant increase in brown non-financial corporate lending under the standard output floor, these results suggest that changes in the composition of non-financial corporate financing may contribute to the modest environmental deterioration observed under the standard regulation.

Taken together, these results point to a potential interaction between the prudential objective of the output floor and the green transition. The standard output floor significantly reduces RWA-density dispersion among IRB banks, but this prudential improvement is accompanied by statistically significant increases in emissions and pollution relative to the no-output-floor benchmark. The brown output floor preserves a statistically comparable reduction in RWA-density dispersion among IRB banks, while no statistically detectable deterioration in environmental outcomes emerges relative to the benchmark. This finding suggests that restricting the floor to brown exposures may mitigate the potential conflict between prudential discipline and the green transition. This conclusion should nevertheless not be interpreted as evidence of an environmental improvement of the brown output floor relative to the standard design, since the direct differences in brown non-financial corporate lending ($p = 0.250$), emissions ($p = 0.276$), and pollution ($p = 0.147$) are not statistically significant. Moreover, this potential environmental benefit comes with a modest prudential cost at the aggregate level, as the brown output floor produces a significantly smaller reduction in system-wide RWA-density dispersion. The brown output floor therefore does not strictly dominate the standard design, but appears to provide a different balance between prudential discipline and environmental considerations.

Figure 7: Evolution of output, emissions and the pollution stock under alternative output-floor regimes.



Notes: The figure plots average evolutions across Monte Carlo repetitions with different random seeds in each scenario.

7 Conclusion

This paper extends the agent-based credit-network framework of Roussel (2025) to investigate the effects of a targeted brown output floor alongside the standard Basel output floor. By distinguishing brown and green non-financial corporate exposures and introducing endogenous environmental dynamics, the model allows us to assess the distributional, macrofinancial, and environmental consequences of both regulatory designs. Our results show that the brown output floor preserves an important prudential property of the standard output floor. Among IRB banks, both policies significantly reduce the dispersion of RWA density, and the difference between their effects is not statistically significant. At the system-wide level, the reduction in RWA-density dispersion is slightly smaller under the brown output floor than under the standard output floor. At the same time, neither regulatory design generates a significant contraction in non-financial corporate lending. Banks instead adjust primarily through the interbank market, where lending declines substantially, suggesting that the output floor mainly reshapes the composition of credit within the banking network rather than inducing a generalized contraction in the financing of the real economy.

The comparison between the two regulatory designs also highlights the potential interaction between prudential regulation and the green transition. While the standard output floor is associated with statistically significant increases in emissions and the pollution stock relative to the no-output-floor benchmark, no statistically detectable environmental deterioration emerges under the brown output floor. Moreover, the targeted floor significantly reshapes the distribution of brown non-financial corporate RWA density among IRB banks by raising regulatory risk weights for the exposures for which the standardized-approach benchmark becomes binding. These findings suggest that targeting the output floor at brown exposures may mitigate the potential conflict between prudential discipline and environmental objectives while preserving its effectiveness in reducing RWA-density dispersion among the banks directly subject to the constraint. This result should nevertheless not be interpreted as evidence that the brown output floor strictly dominates the standard design: the direct differences in emissions and pollution between the two policies are not statistically significant, while the brown design slightly weakens the reduction in system-wide RWA-density dispersion. Rather, our findings suggest that a more targeted implementation of the output floor may provide a different, and potentially more favorable, balance between prudential discipline and the environmental consequences of banking regulation.

From a policy perspective, our results suggest that the design of the output floor could potentially incorporate the environmental composition of banks' credit portfolios without substantially compromising its core prudential objective. Nevertheless, the brown output floor should be viewed as a complement to, rather than a substitute for, existing climate-related prudential and environmental policies. Its implementation would require a robust and harmonized classification of brown exposures, sufficiently granular information on banks' non-financial corporate portfolios, and careful monitoring of possible portfolio reallocation and regulatory-arbitrage effects.

Several extensions could further enrich the analysis developed in this paper. First, future research could investigate the coordination between the brown output floor and other climate-related policy instruments, such as carbon taxation, green credit policies, or climate-related capital requirements. Such an extension would make it possible to assess whether prudential and environmental instruments act as complements or substitutes and whether their joint implementation can improve the balance between financial stability and the green transition. Second, explicitly modeling the household sector would provide a richer representation of the transmission channels operating between banks and the real economy. In particular, household saving, deposit allocation, consumption, and working decisions could generate additional feedback effects between aggregate demand, bank funding, and credit supply. Finally, extending banks' balance sheets to include other risky assets, such as government and non-financial corporate bonds, would allow the model to capture more comprehensively the portfolio reallocation induced by the output floor. Banks facing higher regulatory costs on some credit exposures could substitute toward assets that are less capital-intensive or outside the scope of the floor, potentially generating risk-shifting and regulatory-arbitrage effects that cannot be fully captured when bank portfolios are restricted to non-financial corporate and interbank loans.

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Appendix

Appendix A : Calibration

Table 4 and Table 5 report the full calibration of the model parameters. The minimum regulatory leverage ratio is set to $\text{Lev}^R = 3\%$, in line with the minimum leverage ratio requirement under the Basel III framework (BCBS, 2017).

As in Roussel (2025), firms and banks can adjust their leverage ratios by up to 5% in either direction in each period, which implies $\text{adj}_b^{lev} = \text{adj}_f^{lev} = 0.05$. The magnitude of firms' leverage adjustments is also consistent with the values considered by Riccetti et al. (2013).

Following Roussel (2025), each firm can approach up to $\chi = 3$ banks when seeking corporate financing. Accordingly, the maximum amount of corporate credit that a bank can supply to a single firm is set to three times the average demand for corporate loans, implying $\epsilon^f = 3$. A similar assumption is made for the interbank market, where the maximum amount of credit supplied to an IB-borrower is set to three times the average interbank loan demand, implying $\epsilon^{IB} = 3$.

Compared with Roussel (2025), we assign higher values to the sensitivity of the corporate lending rate to firm and bank leverage, $\gamma^f = 0.06$, and to the sensitivity of the interbank lending rate to the leverage positions of IB-suppliers and IB-borrowers, $\gamma^{IB} = 0.06$. These values improve the model's ability to match the targeted empirical moments. As in Roussel (2025), we set $\zeta = 0.0001$, implying that fluctuations in the interbank lending rate occur within a narrower range than those in the corporate lending rate, consistently with empirical evidence.[8] Consistent with the initial value calibrated by Lauretta (2018), the central bank interest rate is set to $r^{CB} = 2\%$.

In line with Roussel (2025), the fractions of the leverage surplus and deficit used to determine interbank loan supply and demand are set to $\theta_{IB}^{sup} = 0.9$ and $\theta_{IB}^{dem} = 0.19$, respectively. The sensitivity of standardized credit risk to IB-borrower insolvency risk is set to $\Upsilon = 0.5$.

The operating cost of bank capital is set to $c = 0.02$, ensuring that a bank without lending

[8] Interest-rate data are available from the Federal Reserve Bank of St. Louis (FRED) database. For example, U.S. interbank and corporate lending rate series are available at https://fred.stlouisfed.org/series/IR3TIB01USQ156N and https://fred.stlouisfed.org/series/CILACBQ158SBOG, respectively.

Table 4: Non-environmental parameters calibration

Parameter	Description	Value	Source
MC	Number of Monte Carlo simulation	100	Catullo et al.(2021)
T	Time simulation	1000	Catullo et al.(2021)
M	Number of banks	50	Bargigli et al.(2016)
N	Number of firms	500	Bargigli et al.(2016)
Lev^R	Minimum bank's leverage ratio	0.03	BCBS (2017)
adj_b^{lev}	Adjustment bank's leverage ratio	0.05	Roussel (2025)
ϵ^f	Multiplier of max loan supply for a firm	3	Roussel (2025)
ϵ^{IB}	Multiplier of max loan supply for an IB-borrower	3	Roussel (2025)
χ	Number of potential lenders for a firm	3	Roussel (2025)
r^{CB}	Central bank rate	0.02	Lauretta (2018)
γ^f	Corporate loan rate sensitivity to firm and bank leverage	0.06	Authors' selection
γ^{IB}	IB-loan rate sensitivity to leverage of IB-supplier and IB-borrower	0.06	Author's selection
ζ	Scale parameter of IB-borrower's contribution in IB-rate	0.0001	Roussel (2025)
θ_{IB}^{sup}	Fraction of leverage surplus used for IB-supply	0.9	Roussel (2025)
θ_{IB}^{dem}	Fraction of leverage surplus used for IB-demand	0.19	Roussel (2025)
Υ	Sensitivity of SA credit risk to IB-borrower insolvency risk	0.5	Roussel (2025)
c	Operating cost of bank's capital	0.02	Bargigli et al.(2016)
ρ^f	Share of firm's profits used for taxes and dividends	0.2	Roussel (2025)
ρ^b	Share of bank's profits used for taxes and dividends	0.2	Gurgone and Iori (2022)
ω	Prudential cost of bank's capital	1	Roussel (2025)
ν	Capital requirements of prudential regulator	0.105	BCBS (2017)
ξ_f	Default probability sensitivity to firm loan exposure	4.595	Roussel (2025)
ξ_b	Default probability sensitivity to IB-borrower loan exposure	5.989	Roussel (2025)
φ_f	Default probability sensitivity to firm loan exposure	0.5	Roussel (2025)
φ_b	Default probability sensitivity to bank loan exposure	0.5	Roussel (2025)
$\overline{\text{Exp}^f}$	Benchmark firm loan exposure for IRB risk-weight	2	Roussel (2025)
$\overline{\text{Exp}^{No-Liq}}$	Benchmark bank loan exposure for IRB risk-weight	20	Roussel (2025)
λ^{IRB}	IRB choice sensitivity to bank's net-worth	0.125	Author's selection
η	CAR threshold for bank's bankruptcy	0.045	BCBS (2017)
κ^{Lev}	Output floor constraint in banks' leverage	0.05	Authors' selection
ϕ	Scale parameter in firm's production function	3	Bargigli et al.(2016)
β	Firm's production sensitivity to physical capital	0.7	Bargigli et al.(2016)
adj_f^{lev}	Adjustment firm's leverage ratio	0.05	Bargigli et al.(2016)
α	Mean of firm's stochastic price	0.05	Authors' selection
$varp$	Variance of firm's stochastic price	0.4	Bargigli et al.(2016)
E_n^0	Minimum initial net-worth of new firm	1	Catullo et al.(2021)
E_n^0	Minimum initial net-worth of new bank	1	Catullo et al.(2021)

Table 5: Environmental parameters calibration

Parameter	Description	Value	Source
sb	initial share of the brown firms	0.53	Authors' selection
ϕ^{emiss}	emission-intensity	0.3	Authors' selection
τ^{emiss}	Proportional emission tax	0.015	Authors' selection
$\lambda_{\tilde{n}}^{\Pi_f}$	New firm sensitivity to brown-green profitability spread	1	Authors' selection
$\lambda_{\tilde{n}}^{deff}$	New firm sensitivity to brown-green default rate	1	Authors' selection
$\lambda_{n_b}^{\Pi_f}$	Brown firm sensitivity to brown-green profitability spread	1	Authors' selection
$\lambda_{n_b}^{deff}$	Brown firm sensitivity to brown-green default rate	1	Authors' selection
$\lambda_{n_b}^{NG}$	Brown firm sensitivity to net marginal abatement gain	10	Authors' selection
ϱ	Unconditional probability of abatement improvement	0.1	Authors' selection
κ^{abat}	Intensity of marginal abatement cost	0.5	Authors' selection
a_{pol}	Beta distribution of climate shocks	2	Authors' selection
b_{pol}	Beta distribution of climate shocks	18	Authors' selection
λ^{pol}	Sensitivity of climate shock probability	0.0513	Authors' selection
ν^{pol}	Curvature of climate shock probability	2	Authors' selection
δ^{pol}	Pollution depreciation rate	$1-(1-0.0035)^4$	Ferrari and Nispi-Landi (2024)
ζ^{pol}	Physical conversion factor	$3/11$	Jondeau et al.(2023)

activity cannot generate positive profits. The shares of firms' and banks' profits allocated to taxes and dividends are set to $\rho^f = \rho^b = 0.2$, close to the values considered by Gurgone and Iori (2022). The regulatory capital requirement is calibrated at $\nu = 0.105$ to account for the minimum capital requirements and the capital conservation buffer under the Basel III framework (BCBS, 2023).

Consistent with this regulatory framework, we assume that a bank cannot operate with a capital adequacy ratio below the minimum Common Equity Tier 1 (CET1) requirement (BCBS, 2023). Accordingly, if a bank's CAR falls below $\eta = 0.045$, the prudential regulator requires the bank to cease its lending activity. In the model, the termination of lending activity is equivalent to bank failure.

As in Roussel (2025), the prudential cost parameter is set to $\omega = 1$, implying that the maximum prudential penalty imposed on an undercapitalized bank amounts to 6% of its net worth. The sensitivities of default probabilities to firm and bank loan exposures are calibrated at $\xi_f = \log(1/0.01 - 1) \simeq 4.595$ and $\xi_b = \log(1/0.0025 - 1) \simeq 5.989$, respectively, to generate an IRB RWA density distribution consistent with the empirical facts. Benchmark loan exposures are set to $\overline{\text{Exp}^f} = 2$ and $\overline{\text{Exp}^{No-Liq}} = 20$ to ensure consistency with the standardized-approach risk-weight calculations. The sensitivities of default probabilities to firm and bank loan exposures are further parameterized by $\varphi_f = \varphi_b = 0.5$.

The sensitivity of banks' IRB adoption decisions to their net worth is set to $\lambda^{IRB} = 0.125$ to match the empirical share of IRB exposures in European banks' asset portfolios. The sensitivity of banks' target leverage adjustment to the output-floor constraint is set to $\kappa^{Lev} = 0.05$. This calibration gives the output-floor constraint the same adjustment magnitude as the mechanism driven by banks' past profitability.

Following Riccetti et al. (2013) and Bargigli et al. (2016), we set the scale parameter and the elasticity of physical capital in firms' production function to $\phi = 3$ and $\beta = 0.7$, respectively. We also retain the variance of firms' stochastic prices used by these authors, $varp = 0.4$, while setting their mean to $\alpha = 0.05$ to improve the model's ability to match the targeted empirical moments.

The minimum initial net worth of newly entering firms and banks is set to $E_n^0 = E_m^0 = 1$, consistent with the initialization adopted by Catullo et al. (2021).

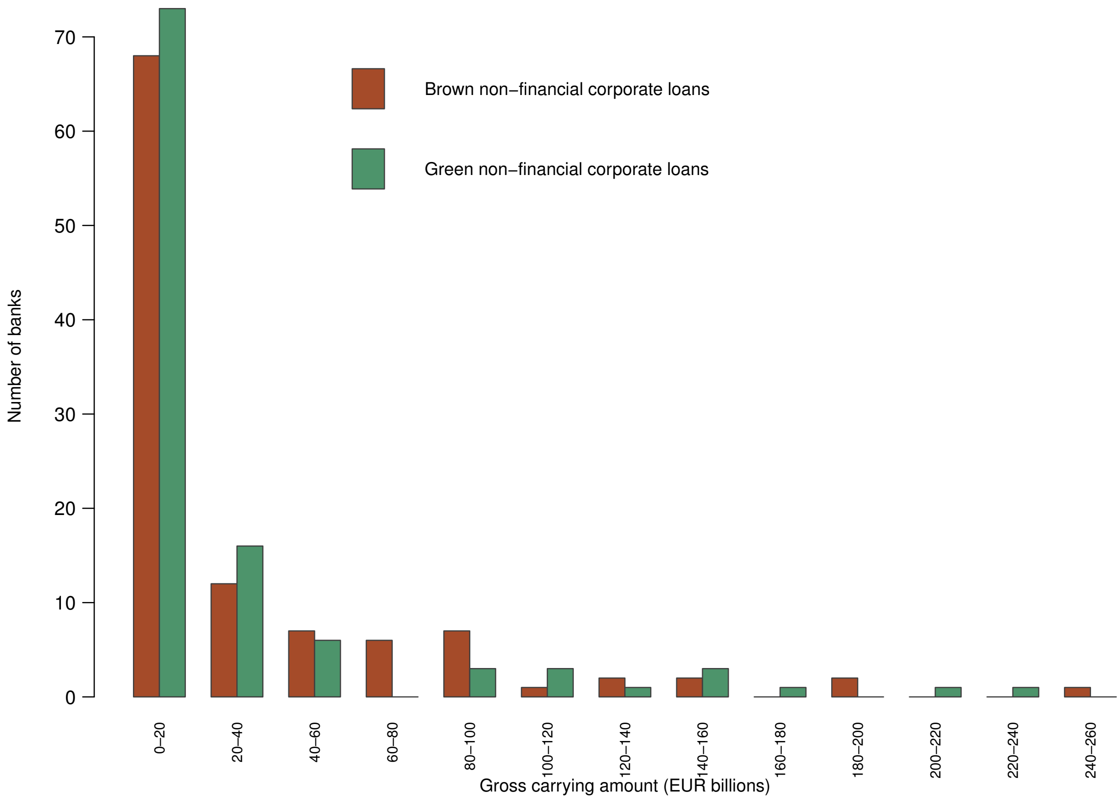
Regarding the environmental parameters reported in Table 5, the initial share of brown firms is set to $s^b = 0.53$ to match the average share of polluting loans estimated from the EBA EU-wide Transparency Exercise using the NACE/CPRS classification. The emissions intensity parameter is set to $\phi^{emiss} = 0.3$ to generate an annual volume of European CO_2 emissions, expressed in $MtCO_2$, consistent with the magnitude observed in the data. The proportional emissions tax is set to $\tau^{emiss} = 0.015$ to reproduce the empirical spread of average non-performing loans between brown and green non-financial corporate.

The sensitivities of new firms' technology choices and surviving brown firms' decisions to relative brown-green profitability and default rates, $\lambda_{\tilde{n}}^{\Pi_f}$, $\lambda_{\tilde{n}}^{deff}$, $\lambda_{n_b}^{\Pi_f}$, and $\lambda_{n_b}^{deff}$, are all set to one. By contrast, the sensitivity of surviving brown firms' abatement decisions to the net marginal gain from abatement is set to $\lambda_{n_b}^{NG} = 10$, thereby assigning greater weight to the economic incentives associated with abatement investment. In addition, the unconditional probability of abatement improvement is set to $\varrho = 0.1$ to capture exogenous incentives for brown firms to improve their abatement technology that are not explicitly modeled. The intensity of the marginal abatement cost is set to $\kappa^{abat} = 0.5$.

The parameters governing the distribution of idiosyncratic climate shocks are set to $a_{pol} = 2$ and $b_{pol} = 18$. Under the assumed Beta distribution, this calibration implies a mean shock severity, conditional on a climate shock occurring, of 10%. The sensitivity of climate-shock probability to pollution is set to $\lambda^{pol} = -\log(1-0.05) \simeq 0.0513$, while the curvature of this relationship is governed by $\nu^{pol} = 2$. The annually pollution depreciation rate is set to $\delta^{pol} = 1-(1-0.0035)^4$, consistently with the quarterly depreciation rate considered by Ferrari and Nispi-Landi (2024). Finally, the physical conversion factor is set to $\zeta^{pol} = 3/11$, following Jondeau et al. (2023).

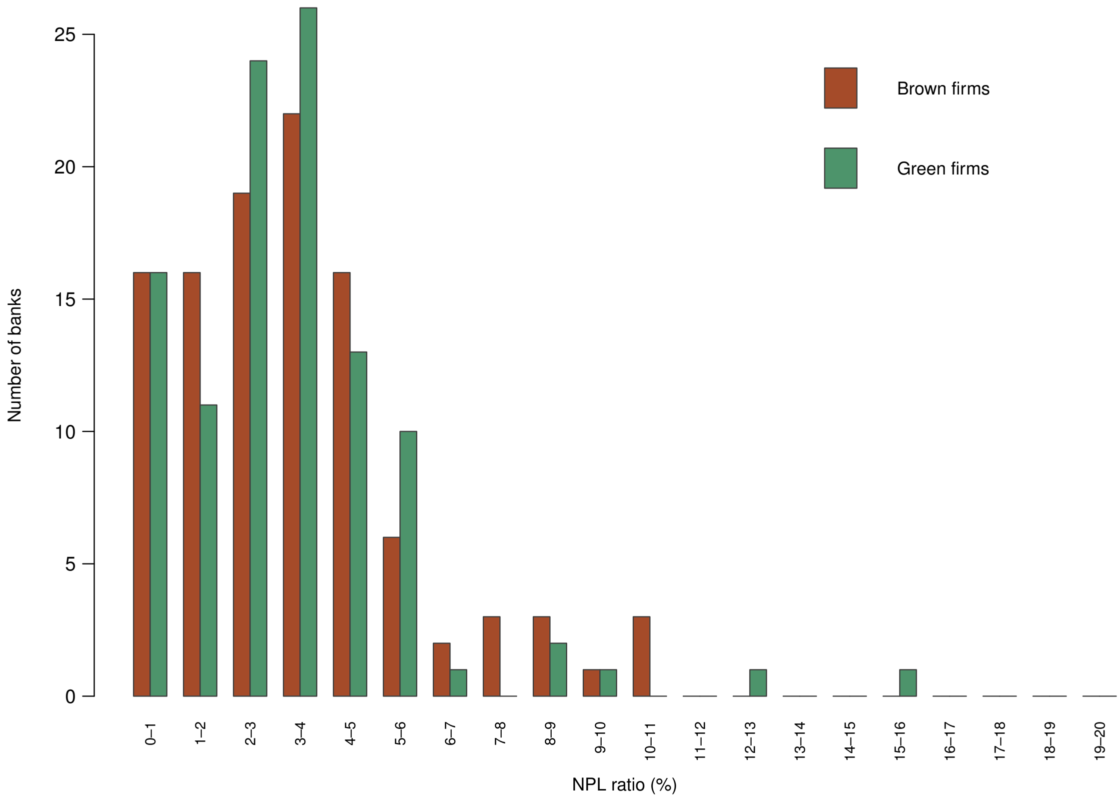
Appendix B : Empirical data used for the matching moments evaluation

Figure 8: Distribution of brown and green non-financial corporate loans.



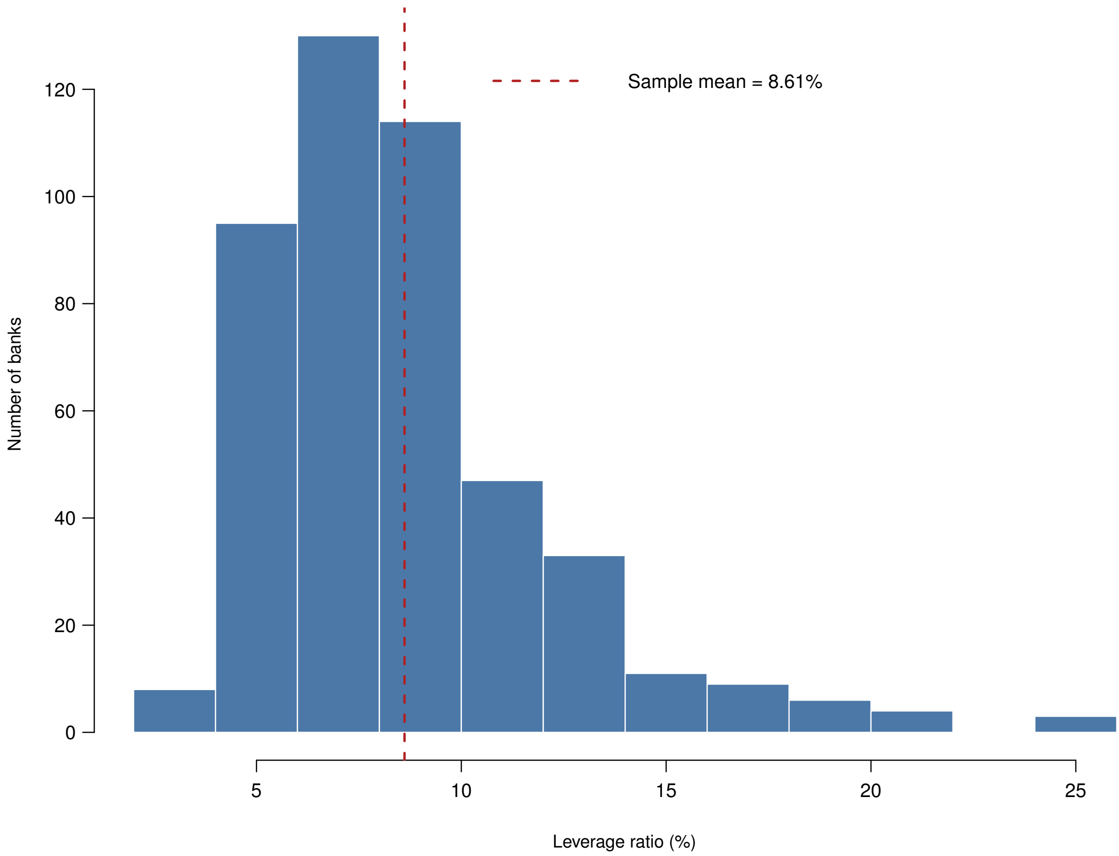
Sources: EBA EU-wide Transparency Exercise (2025) and NACE/CPRS.

Figure 9: Distribution of NPL ratios for brown and green firms.



Sources: EBA EU-wide Transparency Exercise (2025) and NACE/CPRS.

Figure 10: Distribution of bank leverage ratios.



Source: EBA EU-wide Transparency Exercise (2025)