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Green Capital Requirements *

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Abstract

We study the effects of green capital requirements that give preferential capital treatment to clean loans. From a positive perspective, our analysis clarifies the differential effects of green supporting and brown penalizing factors. From a normative perspective, we contrast optimal capital requirements under a classic prudential mandate, which is affected by carbon emissions only through climate-related risks to the banking sector, with those under a broader green mandate that accounts for more general carbon externalities. While climate-related risks that affect bank stability can be optimally addressed by a combination of green supporting and brown penalizing factors, capital regulation is a less effective tool to address carbon externalities that manifest itself outside of the banking sector.

Keywords: Green Finance, Bank Capital Regulation, Transition Risks, Physical Risks, European Green Deal, Capital Requirements, Green Supporting Factor, Brown Penalizing Factor, Climate Risk, Socially Responsible Investment.

JEL Classification: G21, G28

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Climate change has become a central topic for central banks and financial regulators. For example, the ECB strategy review dedicates a whole work stream to climate change. A recent report on the future of finance, commissioned by the Bank of England, devotes an entire chapter to the transition to a low-carbon economy.

At first glance, a climate mandate for financial regulators is not obvious. After all, carbon emissions could in principle be dealt with more directly, for example, through a carbon tax or a cap-and-trade system. However, it has become clear that, for various reasons, these direct solutions usually remain unachievable (see, e.g., Dewatripont and Tirole (2020) and Tirole (2012)). Some policymakers have therefore argued that central banks and financial regulators should step in to fill the void. Others are opposed, so that the issue remains controversial, both in the regulatory sphere and more broadly.

In this paper, we aim to shed light on this issue in the context of bank capital regulation. To do so, we embed carbon emissions into an otherwise standard model of bank capital regulation. As a first step, our positive analysis clarifies the differential effects of lowering capital requirements for clean loans (a "green supporting factor") relative to raising capital requirements for dirty loans (a "brown penalizing factor") on equilibrium bank lending. We then provide a normative analysis that characterizes how optimal capital regulation depends on the nature of climate-related risks and the regulatory mandate. In particular, we distinguish between (1) climate-related risks that affect bank stability through their effect on cash flows of bank-funded firms and (2) externalities that are imposed on parties outside of the banking sector. A regulator with a *prudential mandate* only accounts for risks affecting the financial stability of the banking sector. There is an ongoing debate regarding the size of climate-related risks for financial stability. In our policy analysis, we therefore consider both small and large climate-related risks. A regulator with a broader *green mandate* accounts for general carbon externalities in addition to financial stability in the banking sector.

Our main results are as follows. Regardless of the regulatory mandate, climate-related risks that affect bank stability can be optimally addressed by a combination of green supporting and brown penalizing factors, thereby rationalizing the proposed policy tools. Perhaps surprisingly, if climate risks are moderate in magnitude, optimal regulation can induce banks to reduce lending to clean firms rather than dirty firms, even if only dirty firms are negatively affected by climate risk. In contrast, optimal policies under the two regulatory mandates differ drastically with respect to carbon externalities imposed on firms or agents outside of the banking sector. A prudential regulator does not change its policy in response to such externalities and views dirty lending as desirable as long as it is financially profitable. In contrast, a regulator with a broader green mandate views lending to dirty firms as socially detrimental if externalities are sufficiently large. Capital regulation then becomes a tool to incentivize clean and deter dirty lending. Our results show that such policies are generally costly from a prudential perspective and are limited in their effectiveness to deter dirty lending. We conclude that capital regulation has limited power to address such externalities.

In our model, banks extend loans to a finite mass of two types of borrowers, dirty and clean. As in Oehmke and Opp (2019), there is a tension between financial profitability and social value. Dirty borrowers have access to a more profitable production technology, but they generate significant carbon emissions. Clean borrowers are financially less profitable, but produce lower carbon emissions.[1] Loans to both clean and dirty firms are risky. In particular, with some probability the cash flows generated by both the clean and the dirty firm are low, so that both of them default. In this case, banks cannot repay deposits in full, so that the deposit insurance must step in. Because deposit insurance is not fairly priced, a deposit insurance subsidy arises, distorting banks' investment incentives. Capital requirements then serve to reduce these distortions, a common feature in many models of bank capital regulation following Kareken and Wallace (1978).

We first consider exogenous policy changes in the form of a green supporting factor

[1] Our framework can be easily adjusted to incorporate a third type that generates both no emissions and high cash flows. The main insights are robust.

(i.e., lower capital requirements for clean loans) or a brown penalizing factor (higher capital requirements for dirty loans), starting from a benchmark equal capital requirements for clean and dirty loans. In this baseline scenario, banks prefer financing dirty over clean loans due to their higher profitability. Our analysis highlights that raising capital requirements for dirty loans is not equivalent to lowering capital requirements for clean loans. This can be seen by drawing an analogy to income and substitution effects. The substitution effect is similar for both policies as they both increase the *relative* profitability of clean versus dirty loans. Where the policies differ is with regards to the income affect, i.e., the ability to fund loans with a given amount of bank equity capital. A brown penalizing factor is associated with a negative income effect as it tightens bank balance sheet constraints whereas a green supporting factor is associated with a positive income effect by relaxing overall bank balance sheet constraints. The net effect of green tilts to prudential capital requirements depends on the relative size of the income and substitution effects.

For "small" policy interventions the income effect is the relevant force. As a result, if the marginal loan is clean, a small brown penalizing factor on (inframarginal) dirty loans will cause an increase the balance sheet space taken up by dirty loans and, hence, *crowd out* clean lending. In contrast, a small green supporting factor *crowds in* marginal loans, thereby increasing the number of green projects that receive financing. This shows that, for small interventions, the two tools have directionally different effects on bank lending. In contrast, for large interventions, the two considered policies are qualitatively similar due to the substitution effect: If the change in capital requirements is large enough, as to reverse the banks' profitability ranking of clean versus dirty loans, clean loans receive unambiguously more financing.

Building on this analysis of exogenous policy changes, we characterize how optimal capital requirements are affected by 1) climate-related financial risks for banks and 2) carbon externalities on parties outside of the financial sector. We start with an analysis of how to account for climate-related financial risks for the banking sector under a classic prudential regulatory mandate. The prudential regulator's objective is to maximize the NPV generated by bank-funded firms net of deadweight costs arising from the deposit insurance put. The prudential regulator does not care about carbon emissions per se, so that emissions are reflected in capital requirements only insofar as they correlate with the prudential objective. The prudential regulator responds to climate-related risks (e.g., a reduction in profitability or increase in risk of dirty projects caused by transition risk) by increasing capital requirements for dirty loans, sometimes coupled with a decrease in the capital requirement for clean loans. Notably, when climate-related risks are small, it can be optimal for the prudential regulator to increase capital requirements for dirty loans even if this crowds out lending to marginal clean firms. In this case, the prudential regulator does not act to reduce lending to dirty firms, but simply finds it optimal to require more capital for these loans in order to reduce their deposit insurance put. This prediction changes in the presence of large climate-related risks for banks, in which case the prudential regulator uses capital requirements to change bank's private ranking of loan types and induce them to fund clean firms first.

We then turn to the analysis of externalities generated by bank-funded dirty firms on parties outside the banking sectors. Such externalities could be physical externalities on non-bank funded firms or consumption externalities. While externalities on parties outside the banking sectors can be an important concern for overall economic policy, they are unaccounted for by the traditional prudential objective.

Hence, an active debate has arisen whether financial regulators should consider a broader (green) mandate that directly accounts for such externalities caused by carbon emissions. Under such a mandate, sufficiently large carbon externalities associated with dirty lending will cause the regulator to actively seek to deter funding of dirty firms, independent of financial stability considerations. However, our analysis reveals that capital requirements are an imperfect tool to achieve this goal. In particular, even at capital requirements of 100% banks may still find dirty loans financially profitable (as long as carbon taxes are not in place). As a result, the only way to reduce the funding of dirty firms is to also subsidize clean lending by lowering capital requirements for clean loans. In doing so, the regulator invariably has to sacrifice financial stability. Therefore, whereas capital requirements are an effective tool to address wedges that arise between banks' profit motive and the prudential regulatory objective, they are much more limited in addressing wedges resulting from carbon externalities.

Related literature. To the best of our knowledge, our paper is the first attempt in the literature to study the positive and normative implications of climate change for bank capital regulation. Our framework draws on and contributes to two literatures. First, we add to the literature on prudential bank capital regulation, including, among others, Kareken and Wallace (1978), Rochet (1992), Repullo (2004), Pennacchi (2006), Plantin (2014), Allen et al. (2011), Admati et al. (2011), Bahaj and Malherbe (2020), Malherbe (2020) and Harris et al. (2020). This literature has focused on capital regulation in the presence of distortions introduced by deposit insurance, but it has not taken up the issue of green capital requirements, which is the central focus of our paper. Second, the issue of carbon emissions and other negative externalities that are not internalized by profit-seeking investors is central to the literature on socially responsible investment, including, among others, Heinkel et al. (2001), Hart and Zingales (2017), Chowdhry et al. (2018), Oehmke and Opp (2019), and Landier and Lovo (2020). Broadly speaking, this literature has focused on the effect of investors with socially-minded preferences on firm investment decisions. In contrast, this paper focuses on a setting in which investors do not internalize carbon emissions, creating a role for bank capital regulation to incorporate the carbon intensity of banks' borrowers.

1 Model

We consider a model with two dates, $t = 0, 1$, universal risk-neutrality and no time discounting. There are three types of agents: a continuum of firms with investment opportunities, a continuum of competitive banks, and a regulator who sets capital requirements.

Firms. There is a continuum of cashless firms with total mass normalized to 1. Each firm is of infinitesimal size and born to be one of two types, $q \in \{C, D\}$, which we will refer to as clean and dirty. Firm types are observable. The population fraction of type q is fixed and given by π_q.

Production requires an investment of fixed scale I at $t = 0$ and generates state- and type-dependent cash flow $X_q(s)$ at date $t = 1$. We assume that cash flows for each type q follow a log-normal distribution with parameters μ_q and σ_q, so that the firm's expected cash flow is given by:

$$\overline{X}_q = \exp\left[\mu_q + \sigma_q^2/2\right]. \tag{1}$$

In our baseline model, we assume equal variance parameters, $\sigma_q = \sigma$. Both firm types have positive NPV investment opportunities, $\text{NPV}_q := \overline{X}_q - I > 0$, but dirty firms are more profitable than clean firms,

$$\text{NPV}_D > \text{NPV}_C. \tag{2}$$

While dirty firms are financially more profitable, they produce higher carbon emissions than clean firms, $\phi_D > \phi_C = 0$ (where we normalize carbon emissions of clean firms to zero). This baseline scenario aims to capture that, at least, historically there has been a tension between profitability and sustainability.

Carbon emissions generate both *consumption externalities* (which directly affect the utility of agents in the economy) and *production externalities* (which directly affect the cash flows of other firms). We describe these externalities in more detail in Section 4.

We follow Dewatripont and Tirole (2020) in assuming that Pigouvian taxation of carbon emissions is either absent or imperfect. In the latter case, the firm's cash flows should be interpreted as already incorporating the effect of carbon taxes.[2]

Banks. Firms can raise funds for production by obtaining a loan from a continuum (also of mass one) of competitive and ex-ante identical banks. Each bank is endowed with inside equity $E < I$. Because there is a unit mass of banks, E also corresponds to the aggregate amount of equity in the banking sector.[3] To finance assets A, each bank can raise additional deposit funding D from competitive depositors, resulting in the balance sheet identity

$$A = E + D. \tag{3}$$

Bank capital structure matters because the model features two deviations from the Modigliani-Miller benchmark. First, we assume that outside equity issuance is subject to frictions. For ease of exposition, we assume that the associated cost is prohibitively high, so that bank equity is fixed at E.[4] Second, deposit insurance (or an implicit or explicit bailout guarantee for debt holders) results in an effective subsidy for deposit financing. In our model, deposit insurance is not priced, so that total payouts to bank security holders are increasing in the deposit-to-asset ratio $\frac{D}{A}$. The results would be similar if deposit insurance were priced imperfectly, as in Chan et al. (1992).[5]

[2] Irrespective of the feasibility of directly taxing carbon emissions, the issue of green capital requirement is of significant research interest given that regulators around the globe are actively considering such interventions.

[3] The restriction that $E < I$ therefore rules out the case in which all firms can receive funding even if capital requirements are set to 100% for all loans.

[4] Banks could theoretically pay out part of their equity capital as dividends. However, as we will see below, this will never be optimal for banks under optimal regulation. Our results remain qualitatively unchanged if banks can issue additional outside equity at a positive but non-prohibitive marginal cost.

[5] One may wonder why we assume both a cost of outside equity and a (private) benefit of debt, given that any one of these frictions would be sufficient to ensure that banks favor debt financing. The reason is that, in the absence of costly equity issuance, the regulator could eliminate bailout distortions by setting capital requirements to 100%. Such an analysis would neither be theoretically interesting nor would it appear to have particular practical relevance.

The bankers' objective is to maximize the value of their equity

$$V = \max_{e,\mathbf{w}} E\left[1 + r_E\left(\mathbf{w},e\right)\right], \tag{4}$$

where we define $e := \frac{E}{A}$ as the bank's equity ratio and $r_E\left(\mathbf{w},e\right)$ as the bank's expected return on equity (ROE), and where $\mathbf{w} = \left(w_C, w_D\right)$ denotes the vector of bank loan portfolio weights for clean and dirty loans, respectively. Given that bank equity E is fixed, this objective function boils down to maximizing bank ROE, consistent with what bank managers commonly state as their objective in practice. In our risk-neutral setting, any ROE exceeding 0 should be interpreted as a scarcity rent rather than a risk premium.

Bank Regulator. The bank regulator sets loan capital requirements $\underline{e}_q$ as a function of the (observable) firm type q.[6] Given a bank's loan portfolio weights w_q, the bank then faces an equity-ratio constraint of the form

$$e \geq e_{\min}\left(\mathbf{w}\right) := \sum_q w_q \cdot \underline{e}_q. \tag{5}$$

Capital requirements have two effects. First, higher capital requirements reduce transfers from the deposit insurance fund. When analyzing optimal capital requirements in Section 4, we will follow Farhi and Tirole (2020) by assuming that these transfers are associated with a deadweight cost (due to a positive shadow cost of public funds). Second, a higher capital requirement for a firm of type q affects banks' loan decisions and, therefore, the mass of funded firms, ω_q.

2 Equilibrium for Exogenous Capital Requirements

We start by characterizing the banking sector equilibrium for exogenously given capital requirements. This analysis will form the basis of our analysis of green tilts to capital

[6] It is not crucial that firm types are perfectly observable. All results continue to hold if the regulator observes a noisy signal of firm type.

requirements in Section 3 and optimal green capital requirements in Section 4. The analysis in this subsection draws on Harris et al. (2020), and we therefore present the results in a heuristic fashion.

We first characterize optimal leverage decisions by individual banks and then turn to the equilibrium loan decisions of the banking sector as a whole.

Result 1 *Banks go to the regulatory leverage constraint* $e^* = e_{\min}(\mathbf{w}^*)$.

Result 1 states that banks maximize the amount of deposit funding. This is optimal because deposit insurance acts like a subsidy for deposit funding. Given competitive pricing of deposits, the *ex-ante* value of this deposit insurance put is passed on to bank equityholders.[7]

It is useful to frame the banking sector equilibrium in terms of aggregate bank equity. Bank equity E is the scarce resource in the economy. Therefore, drawing an analogy to demand theory, a firm borrowing from a bank is similar to a consumer, and the relevant consumption good is units of bank equity (i.e., space on the bank's balance sheet). Specifically, when a firm demands a loan of size I, this translates into demand for $I\underline{e}_q$ units of bank equity.

Given objective function (4), banks rank borrowers according to the maximum ROE associated with loan to the borrower, which is determined by the maximum interest rate the borrower is willing to pay. As in standard demand theory, the demand curve is then characterized by reservation prices, in the form of the maximum return on equity that a borrower can offer to a bank.

Result 2 *At the maximum interest rate that a borrower of type q is willing to pay, the bank equityholders' expected ROE is given by*

$$r_q^{\max}\left(\underline{e}_q\right) = \frac{NPV_q + PUT_q\left(\underline{e}_q\right)}{I\underline{e}_q}, \tag{6}$$

[7] Bank equityholders, in turn, may pass on some of this subsidy to firms via the pricing of loans.

where $PUT_q\left(\underline{e}_q\right)$ denotes the contribution of the loan to the bank's deposit insurance put.

$$PUT_q\left(\underline{e}_q\right) = \mathbb{E}\left[\max\left\{I(1-\underline{e}_q) - X_q(s), 0\right\}\right], \tag{7}$$

At the borrower's reservation interest rate, all expected surplus generated by the loan accrues to bank equityholders.[8] This surplus consists of the NPV of the firm's project and the value of the deposit insurance put associated with the loan under maximum leverage. Given the log-normal cash flow distribution, the value of the deposit insurance put can be readily determined using the Black-Scholes formula (Merton (1977)).

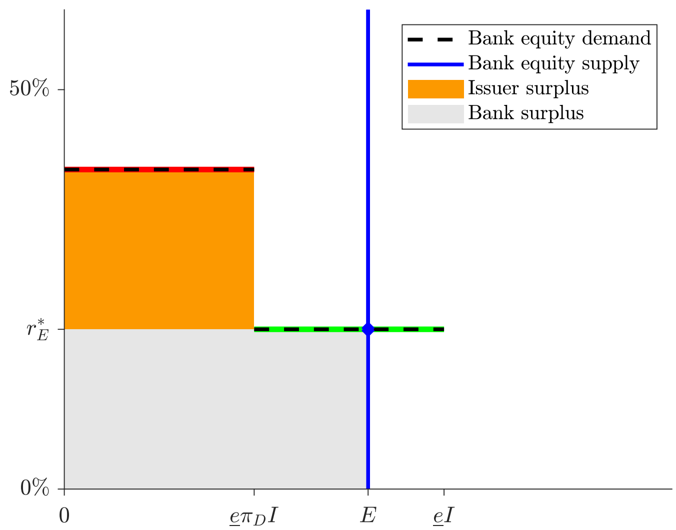


Figure 1. Banking Sector Equilibrium. This figure illustrates the banking sector equilibrium for equal capital requirements of $\underline{e}$ for both types of firms. The equilibrium ROE is denoted by r_E^*.

Because banks behave competitively, they typically cannot extract all surplus from borrowers. Instead, the equilibrium return on bank equity, r_E^*, is pinned down by the intersection of the aggregate demand for bank equity (from funded loans) and its (fixed) supply. The resulting equilibrium is illustrated in Figure 1. Given two borrower types with different reservation prices, the demand curve is a step function. In the illustrated equilibrium, dirty (red) borrowers are fully funded (they are inframarginal), whereas

[8] If borrowers had access to non-bank financing, say via a competitive bond market, then this outside option would pin down the maximum interest rate the borrower is willing to pay for a bank loan. For simplicity, in our model, the outside option is not to invest at all and therefore zero.

borrowers of the clean (green) type are only partially funded (they are marginal). The loan rate for the marginal green borrowers are set such that all surplus accrues to banks (i.e., there is no consumer surplus for marginal loans). Inframarginal borrowers, on the other hand, obtain some consumer (or "issuer") surplus. More generally, we obtain

Result 3 *All borrowers with $r_q^{max} > r_E^*$ are fully funded by banks. Marginal borrower types, satisfying $r_q^{\max} = r_E^*$, are partially funded. The banking sector's equilibrium ROE satisfies:*

$$r_E\left(\mathbf{w}^*, e_{\min}\left(\mathbf{w}^*\right)\right) = r_E^*. \tag{8}$$

This result highlights the importance of the marginal borrower type, which pins down r_E^* and, hence, the funding terms and loan allocation to all inframarginal types $r_q^{\max} > r_E^*$. Which type is marginal depends not only on exogenous firm characteristics (such as the firm's NPV, and the capitalization of the banking sector) but also on the regulator's choice of capital requirements.

3 Green Tilts to Capital Requirements

We now investigate the effects of (exogenous) green tilts to capital requirements. Green tilts can take the form of a reduction in the capital requirement for clean loans (a *green supporting factor*) or an increase in capital requirement for dirty loans (a *brown penalizing factor.*) For expositional clarity, we consider a benchmark policy regime with equal capital requirements for dirty and clean loans ($\underline{e}_C = \underline{e}_D = \underline{e} < 1$) and study the effects of green tilts relative to this benchmark.

In the benchmark equilibrium with equal capital requirements, loans to dirty firms rank strictly higher in the aggregate demand curve (i.e., $r_D^{\max}\left(\underline{e}\right) > r_C^{\max}\left(\underline{e}\right) > 0$), because dirty firms are financially more profitable than clean firms (as illustrated in Figure 1). Accordingly, if bank capital is very scarce ($E < \pi_D \underline{e} I$) the marginal borrower type is dirty and no clean loans are funded. For intermediate levels of bank capital ($\pi_D \underline{e} I < E < \underline{e} I$), all dirty firms are funded, and the marginal loan is extended to a clean firm (the case presented in Figure 1). Finally, in the (somewhat less interesting) case of abundant bank capital, $E > \underline{e}I$, both dirty and clean firms are fully funded.

To analyze the effects of green tilts to capital requirements, it is instructive to interpret a change in the capital requirement for one type of loan as a change in the relative prices of bank balance sheet space for clean and dirty loans. Therefore, in analogy to standard demand theory, we can characterize the effects of green tilts in terms of *income* and *substitution effects*. The substitution effect captures that a green tilt reduces the *relative* price of providing green loans, irrespective of whether the green tilt consists of a green supporting or a brown penalizing factor. However, the two policies differ with respect to the income effect. Whereas a brown penalizing factor constrains bank balance sheet space, akin to a negative income effect, a green supporting factor frees up balance sheet space. In our setting, the relative magnitude of income and substitution effects is governed by the size of the intervention. Since dirty loans rank strictly higher under equal capital requirements ($r_D^{\max}(\underline{e}) > r_C^{\max}(\underline{e})$, as illustrated in Figure 1), marginal changes to capital requirements do not alter the ranking of borrowers. Therefore, small interventions work solely through the income effect and only affect lending to the marginal borrower type. Large interventions that change the ranking of borrowers induce a substitution effect (in addition to the income effect).

3.1 Brown Penalizing Factor

To consider the effects of a brown penalizing factor, it is useful to start with a small interventions (i.e., a marginal increase in the capital requirement for dirty loans relative to the benchmark with equal capital requirements). The case of intermediate bank capital $E \in (\pi_D \underline{e}I, \underline{e}I)$, plotted in the left panel of Figure 2, is most interesting. In this case, a marginal increase in the cost of lending to dirty firms leads to crowding out of lending to clean firms. Relative to the benchmark (dashed red line), a higher capital requirement for dirty loans reduces their attractiveness and results in a downward shift in the dirty borrower's reservation price (from the dashed to the solid red line), without inducing a change in the ranking of types. In addition, because funding the same number of dirty loans now requires more bank equity, the dirty-loan segment of the demand curve lengthens. As a result, less equity is left over to fund clean loans (a rightward shift of the dashed to the solid green line), resulting in a reduction in lending to clean firms.

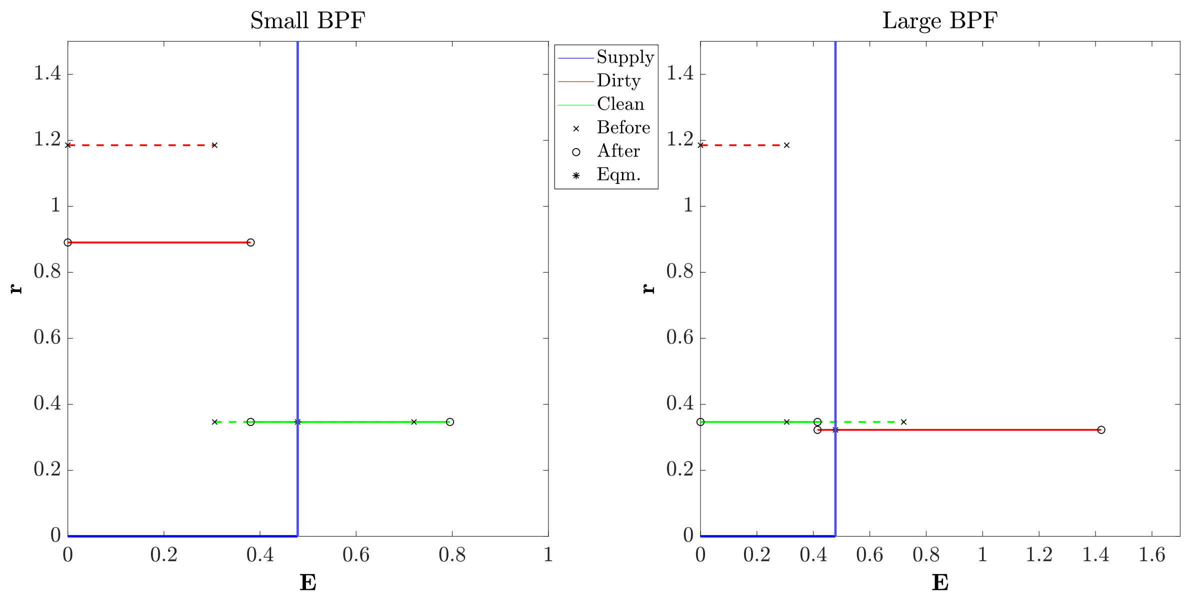


Figure 2. Brown penalizing factor. The figure illustrates the effect of adding a brown penalizing factor to the benchmark equilibrium. The left panel illustrates the equilibrium impact of a small brown penalizing factor that leaves the relative ranking of firm types unchanged. The right panel plots the equilibrium impact of a large brown penalizing factor that reverses the relative ranking of firm types. Dashed lines and x's denote the benchmark equilibrium. Solid lines and o's denote the equilibrium after the introduction of the brown penalizing factor.

If the brown penalizing factor is sufficiently large, the ranking of clean and dirty loans in terms of the borrower reservation price is reversed, so that $r_C^{\max} > r_D^{\max}$ post intervention. This case is illustrated in the right panel of Figure 2. In this case, the substitution effect implies that banks first exhaust all clean lending opportunities before they start funding of dirty firms. Therefore, clean lending increases, and dirty lending decreases. This result is driven by both the substitution effect (clean loans get funded first) and the income effect (the lengthening of the dirty-loan segment of the demand curve).

We summarize the effects of the introduction of a brown penalizing factor in Proposition 1. Part 1 of the proposition characterizes the effects of a marginal brown penalizing factor (including the cases of very scarce or abundant bank capital, which we omitted for brevity in the discussion above). Part 2 of the proposition characterizes the effects of a large brown penalizing factor.[9]

Proposition 1 (Brown Penalizing Factor) *Relative to a benchmark with equal capital requirements for clean and dirty loans:*

1. *The effect of a marginal increase in capital requirements for dirty loans (marginal BPF) depends on the capitalization of the banking sector:*
   (a) *If $E < \pi_D \underline{e} I$, a marginal BPF only reduces lending to dirty firms.*
   (b) *If $E \in (\pi_D \underline{e} I, \underline{e} I)$, a marginal BPF only reduces lending to clean firms.*
   (c) *If $E > \underline{e} I$, a marginal BPF does not affect lending.*
2. *If the increase in capital requirements for dirty firms exceeds a cut-off $\Delta_{BPF} > 0$, characterized by $r_D^{\max}(\underline{e} + \Delta_{BPF}) = r_C^{\max}(\underline{e})$, lending to clean firms increases whereas lending to dirty firms decreases.*

3.2 Green Supporting Factor

We now turn to the introduction of a clean supporting factor. Mirroring the analysis of the brown penalizing factor, we initially consider the introduction of a small green supporting factor.

As before, the intermediate case $E \in (\pi_D \underline{e} I, \underline{e} I)$ is the most interesting. In this case, a small decrease in the capital requirement for clean loans unambiguously increases

[9] To reduce the number of cases in part 2 of the proposition, we assume that the reservation price for clean loans exceeds the reservation price for dirty loans when the capital requirement for dirty loans is raised to 100%, i.e., $r_D^{\max}(1) < r_C^{\max}(\underline{e})$. This assumption is satisfied if the mean productivity of dirty firms μ_D is sufficiently close to that of clean firms μ_C.

funding of clean firms, as illustrated in the left panel of Figure 3. While the dirty-loan segment of the demand curve is unchanged, the clean-loan segment shifts upward (albeit without changing the relative ranking of borrower reservation prices) and shortens. The upward shift reflects that clean loans become relatively more attractive in terms of their reservation price, whereas the shortening of the clean-loan segment reflects that each clean loan now requires less capital. As long as the ranking of reservation prices does not change, the equilibrium effect is driven entirely by the income effect (i.e., the shortening of the clean-loan segment). Therefore, some previously unfunded clean firms are now able to obtain funding. The funding of dirty firms is unaffected.

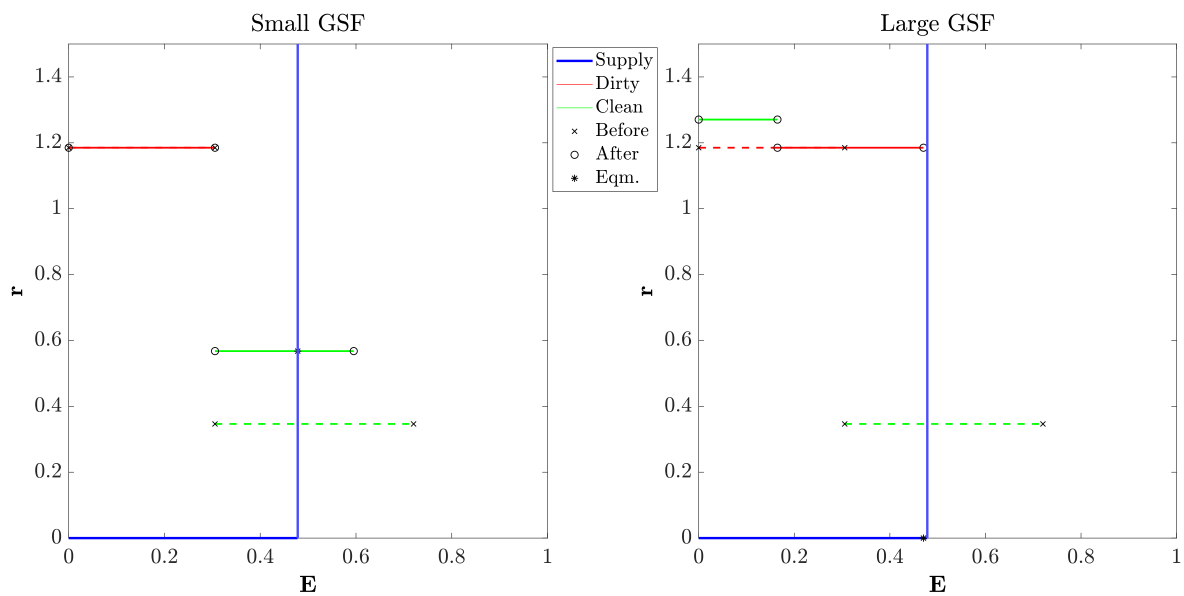


Figure 3. Green supporting factor. The figure illustrates the effect of adding a green supporting factor to the prudential optimum. The left panel illustrates the equilibrium impact of a small green supporting factor that leaves the relative ranking of firm types unchanged. The right panel plots the equilibrium impact of a large green supporting factor that reverses the relative ranking of firm types. Dashed lines and x's denote the benchmark prudential equilibrium. Solid lines and o's denote the equilibrium after the introduction of the green supporting factor.

We now turn to a green supporting factor that is large enough to reverse the relative ranking of clean and dirty loans, so that $r_C^{\max} > r_D^{\max}$ post intervention. This case is illustrated in the right panel of Figure 3. For clean firms, the income and the substitution effect both push towards strictly more financing. The clean-loan segment of the demand curve shifts upward and to the left, so that after the intervention all clean loans are funded. For dirty loans, the income and substitution effects work in opposite directions. The dirty-loan segment shifts to the right (substitution effect) but this shift is attenuated by the shortening of the clean-loan segment (income effect). After introduction of the large green supporting factor, dirty loans take up the balance sheet space that remains after all dirty loans have been funded and, in contrast to the benchmark, dirty loans are only partially funded.

We summarize the effects of a green supporting factor, including the cases of very scarce or abundant bank capital, in Proposition 2.

Proposition 2 (Green Supporting Factor) *Relative to a benchmark with equal capital requirements for clean and dirty loans:*

1. *The effect of a marginal decrease in capital requirements for clean loans (marginal GSF) depends on the capitalization of the banking sector:*
   (a) *If $E \in (\pi_D \underline{e} I, \underline{e} I)$, a marginal GSF increases lending to clean firms.*
   (b) *A marginal GSF has no effect on bank lending otherwise.*
2. *If the decrease in capital requirements for clean firms exceeds a cut-off $\Delta_{GSF} > 0$, characterized by $r_D^{\max}(\underline{e}) = r_C^{\max}(\underline{e} - \Delta_{GSF})$, lending to clean firms increases whereas lending to dirty firms decreases, strictly so if not all firms are financed post intervention.*

In sum, Propositions 1 and 2 show that, for small interventions, brown penalizing and green supporting factors have quite different effects, driven by opposite income effects. For large interventions, on the other hand, the substitution effect becomes dominant, so that their effects are qualitatively similar. However, quantitative differences remain. Comparing lending to dirty firms in the respective right panels of Figures 2 and 3 reveals that a much larger fraction of dirty firms is funded in the case of a large green supporting factor. This is a consequence of the positive income effect associated with the green supporting factor.

4 Optimal Capital Requirements

Up to now, our analysis has focused on two specific interventions, the brown penalizing and the green supporting factor, starting from a benchmark equilibrium with exogenous symmetric capital requirements for clean and dirty loans. In this section, we take the analysis a step further by characterizing optimal capital requirements and how these are affected by climate-related risks. We distinguish between two types of regulatory mandates: In our benchmark analysis, we consider the traditional *prudential regulator*, who only cares about climate-related risks in so far as these risks affect the trade-off between alleviating capital rationing and financial stability. We then consider a *green regulator* with a broader mandate that also accounts for carbon externalities.

4.1 The Principles of Prudential Regulation

The prudential regulator follows a traditional prudential mandate that trades off the financial value (or NPV) created by bank lending against the deadweight costs generated by deposit insurance. For simplicity, we assume that the deadweight cost of the deposit insurance put is linear in the size of the fiscal transfer to the banking sector, reflecting a constant marginal cost of public funds λ. The regulator's objective function is therefore

$$\max_{\underline{\mathbf{e}}} \Omega_P = \max_{\underline{\mathbf{e}}} \sum \omega_q \left(\underline{\mathbf{e}}\right) \left[\mathrm{NPV}_q - \lambda \cdot \mathrm{PUT}_q(\underline{e}_q)\right], \tag{9}$$

where the notation $\omega_q\left(\underline{\mathbf{e}}\right)$ and $\mathrm{PUT}_q(\underline{e}_q)$ highlights the dependence of bank funding decisions and the deposit insurance put on the capital requirements for clean and dirty firms, $\underline{\mathbf{e}} = (\underline{e}_C, \underline{e}_D)$.

To characterize optimal prudential capital requirements, it is instructive to rewrite the regulator's objective function as

$$\max_{\underline{\mathbf{e}}} \Omega_P = E \max_{\underline{\mathbf{e}}} \sum \tilde{\omega}_q \left(\underline{\mathbf{e}}\right) \mathrm{PPI}_q(\underline{e}_q), \tag{10}$$

where $\tilde{\omega}_q \in [0,1]$ reflects the fraction of total bank equity that the banking sector allocates to funding type q, and where $\mathrm{PPI}_q(\underline{e}_q)$ denotes the *prudential profitability index*. In analogy to the banker's maximal ROE given in equation (6), the PPI reflects the surplus created per unit of bank equity as seen from the prudential regulator's perspective,

$$\mathrm{PPI}_q(\underline{e}_q) = \frac{\mathrm{NPV}_q - \lambda \cdot \mathrm{PUT}_q(\underline{e}_q)}{I \underline{e}_q}. \tag{11}$$

Comparing equations (6) and (11), we see that there are two main differences between the regulator's PPI and the bankers' maximal ROE. First, the deposit insurance put enters with opposite sign, reflecting the wedge between prudential preferences and those of the banking sector. Second, while banks take ROEs as given, the regulator internalizes that the PPIs for each type are affected by the chosen capital requirement.

We assume that the cost of public funds is sufficiently high, $\lambda > \max_q \frac{\mathrm{NPV}_q}{\mathrm{PUT}_q(0)}$, which ensures that the PPI is bounded above for each type.[10] Then the capital requirement that maximizes the PPI for type q, $\underline{e}_q^{\mathrm{PPI}}$, satisfies the first-order condition

$$\frac{1}{\underline{e}_q} \left[\mathrm{NPV}_q - \lambda \mathrm{PUT}_q\right] = \lambda \left| \frac{\partial \mathrm{PUT}_q}{\partial \underline{e}_q} \right|. \tag{12}$$

The left-hand side captures the marginal benefit of relaxing in capital requirements. More firms can be financed, resulting in additional prudential surplus. The right-hand side captures the marginal (social) cost of lower capital requirements, in the form of a higher deposit insurance put.

From the regulator's perspective, a borrower with a higher PPI delivers more "bang

[10] If $\lambda < \frac{\mathrm{NPV}_q}{\mathrm{PUT}_q(0)}$, the PPI approaches positive infinity as the capital requirements approach zero.

for the buck" (prudential value per unit of equity capital) and is therefore preferred.

Definition 1 *The regulator's preferred type is the one that achieves the highest possible PPI, i.e.,* $\max_q PPI_q(\underline{e}_q^{PPI})$.

In the baseline case, $\sigma_C = \sigma_D = \sigma$ and $\mu_D > \mu_C$, the prudential regulator's preferred type is the dirty type D. This happens for two reasons. First, dirty loans create larger financial surplus than clean loans, $\text{NPV}_D > \text{NPV}_C$. Second, given equal variance parameters σ, for any capital requirement $\underline{e}$ dirty loans induce a smaller expected transfer from the deposit insurance fund, $\text{PUT}_D\left(\underline{e}\right) < \text{PUT}_C\left(\underline{e}\right)$.

As shown in Proposition 3, the PPI plays an important role for the characterization of optimal prudential capital regulation.

Proposition 3 (Principles of Optimal Prudential Regulation) *Optimal prudential regulation is characterized by the following four principles.*

P1: All bank equity is used to fund loans,

$$\sum_q \omega_q\left(\underline{\mathbf{e}}\right)\underline{e}_q I = E. \tag{13}$$

P2: For sufficiently low levels of bank equity, $E \leq \pi_D \underline{e}_q^{PPI} I$*, the regulator induces banks to lend to its preferred type* D.

P3: If firm type q *is partially funded (there is at most one such type), its capital requirement maximizes* PPI_q,

$$e_q^* = \underline{e}_q^{PPI}. \tag{14}$$

P4: If both firm types are funded, marginal deposit-insurance puts are equalized across types,

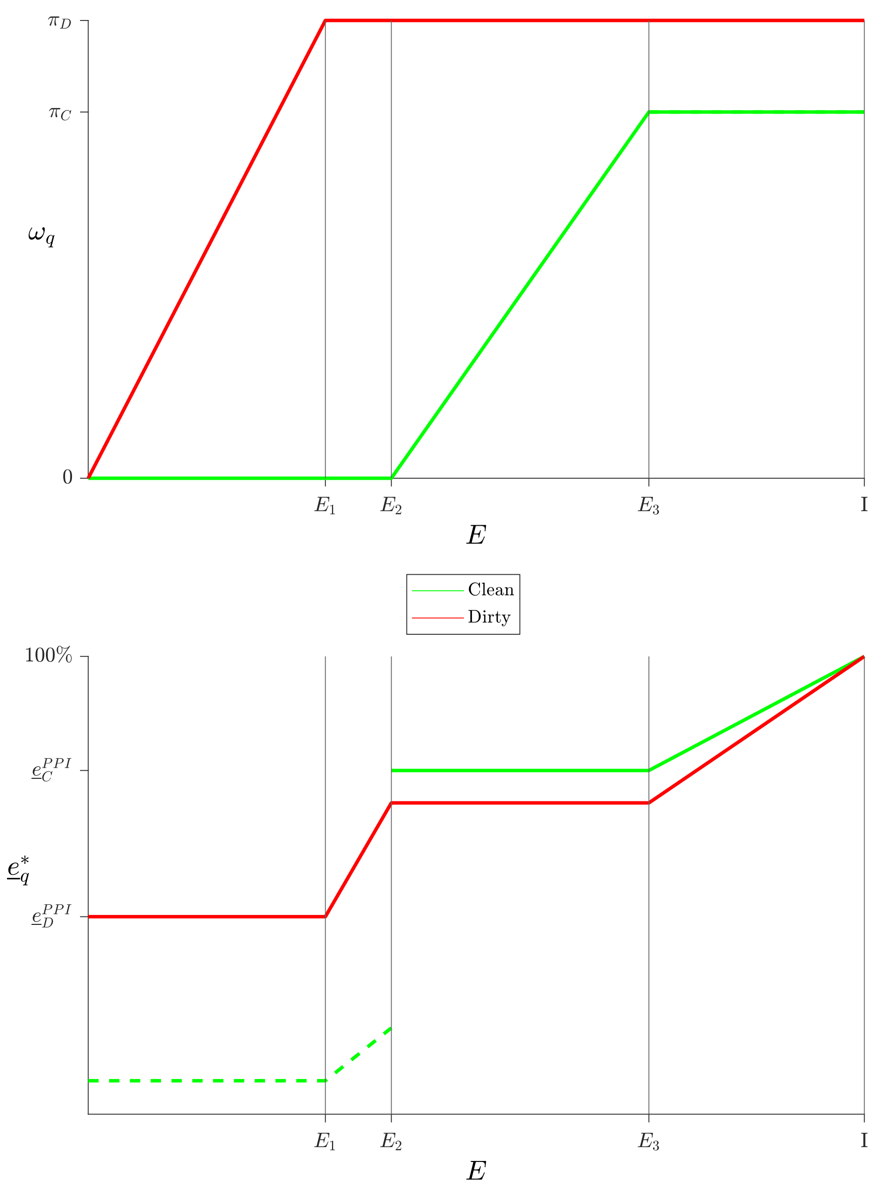
$$\frac{\partial PUT_D}{\partial \underline{e}_D} = \frac{\partial PUT_C}{\partial \underline{e}_C}. \tag{15}$$

Principle P1 states that the equity of the banking sector is fully exhausted. This means that, under optimal prudential regulation, banks do not find it optimal to pay out dividends. Intuitively, this principle helps mitigate the deadweight costs arising from insured deposit financing. Principle P2 says that the first funded type is the regulator's preferred type D. This can always be made incentive compatible for banks by setting a sufficiently high capital requirement for the (unfunded) clean type. Principle P3 states that the optimal capital requirement for the marginally funded type maximizes the PPI, $e_q^* = \underline{e}_q^{\text{PPI}}$. Finally, Principle P4 links capital requirements of inframarginal borrowers with those of marginal borrowers. Specifically, optimality condition (15) requires that the marginal reductions in the deposit insurance put resulting from higher capital requirements are equalized across funded types.

Based on these four principles, Figure 4 highlights 4 distinct regions linking optimum prudential capital regulation to the capitalization of the banking sector E. The lower panel plots optimal prudential capital requirements and the upper panel plots the corresponding funding decisions ω of the banking sector. As can be seen, capital requirements are generally increasing in the capitalization of the banking sector E, which can be interpreted as procyclical capital requirements or, equivalently, countercyclical capital buffers.

For sufficiently scarce equity, $E < E_1 := \pi_D \underline{e}_D^{\text{PPI}} I$, only the regulator's preferred (dirty) type is funded. Since the dirty type is partially funded, $\omega_D < \pi_D$ (see upper panel), Principle P3 applies and the optimum prudential capital requirement maximizes PPI_D, $\underline{e}_D^* = \underline{e}_D^{\text{PPI}}$. To ensure that banks find it incentive compatible to exclusively lend to dirty firms, capital requirements for the (unfunded) clean type must be set sufficiently high so as to ensure that $r_C^{\max}(\underline{e}_C^*) \leq r_D^{\max}(\underline{e}_D^*)$. This IC constraint imposes a lower bound on the capital requirement for clean loans, which is illustrated by the dotted green line. As equity in the banking sector increases, the mass of funded dirty firms increases accordingly, as illustrated in the upper panel of Figure 4. Once $E = E_1$, all dirty firms

Figure 4. Optimal prudential capital regulation. This figure plots equilibrium funding decisions (upper panel) and capital requirements (lower panel) under optimal prudential bank capital regulation. Clean firms and capital requirements are plotted in green, dirty in red. The dotted green line indicates the lower bound on the capital requirement for (unfunded) clean firms when only dirty loans are funded and the capital requirement for dirty loans is set to e_D^*. This lower bounds satisfies $r_C^{\max}(\underline{e}_C) = r_D^{\max}(\underline{e}_D^*)$.



are funded, $\omega_D = \pi_D$.

In the second region, $E \in (E_1, E_2)$, dirty firms are fully funded, $\omega_D = \pi_D$. However, clean firms remain unfunded (see upper panel). Intuitively, once all dirty lending opportunities in the economy have been exhausted, the marginal benefit of funding the next best investment opportunity, the clean type, is lower by a discrete amount. Therefore, it is initially optimal to use additional equity in the banking sector to reduce the deposit insurance put associated with funding dirty firms, rather than inducing banks to fund clean firms. In this region, Principle P1 pins down optimal prudential capital requirements for the dirty type, $\underline{e}_D^* = \frac{\pi_D E}{I}$ (see lower panel).[11]

Once the capitalization of the banking sector reaches $E = E_2$, the marginal reduction in the deadweight cost associated with the deposit insurance put is equal to the marginal value of funding a clean firm. Therefore, in region 3, $E \in (E_2, E_3)$, it becomes optimal to induce banks to fund clean firms, which then become the marginal type. The clean capital requirement is, therefore, pinned down by Principle P3, so that $\underline{e}_C^* = \underline{e}_C^{PPI}$. The capital requirement for the inframarginal dirty type is determined by Principle P4, the equalization of marginal puts.

Finally, in region 4, $E > E_3$, both types are fully funded $\omega_q = \pi_q$ (see upper panel). In this region, banking sector equity does not affect production decisions in the economy. Therefore, any additional equity is used to phase out the deadweights costs arising from deposit insurance. Principles P1 and P4 jointly pin down the optimal capital requirements for clean and dirty types.

4.2 The Effect of Climate-Related Risks

Climate-related risks operate through various channels that are not necessarily mutually exclusive, such as physical risks or transition risks. For the purpose of our analysis, it will be useful to distinguish between three broad categories of climate-related risks:

1. Changes in economic prospects correlated with firm type (but unrelated to funding decisions of the banking sector)

[11] Optimum clean capital requirements are again set to ensure that $r_C^{\max}(\underline{e}_C^*) < r_D^{\max}(\underline{e}_D^*)$, see green dotted line in the lower panel. Because dirty capital requirements are increasing in E in this region, the lower bound for clean capital requirement is increasing too to satisfy the bankers' IC constraint.

2. Production externalities (stemming from funding decisions by the banking sector)

3. Consumption externalities (stemming from funding decisions by the banking sector)

We start by analyzing climate-related risks that affect the relative prospects of dirty and clean firms. Most prominently, this includes regulatory transition risk (i.e., the effect of future environmental regulation, say a ban of gasoline cars or the introduction of significantly higher carbon taxes). When transition risk materializes, it lowers the cash flows (and increases the downside risk) of dirty relative to clean firms. Technological risks (technological obsolescence), stakeholder risks (changing preferences of consumers and employees) or legal risks (legal exposures due to climate risks) have similar financial ramifications.

In our model, these effects can be understood as a comparative static analysis relating to the parameters of the cash-flow distribution. In particular, given our assumption of a lognormal cash-flow distribution, we capture transition risks as decreases in the expected cash flow of dirty firms $\overline{X}_D$ and/or increases in their volatility σ_D, holding $\overline{X}_D$ constant.[12] Following the structure of Section 3, we initially consider small changes, now relative to the prudential optimum.

Proposition 4 (Optimal Marginal Policy Adjustments) *A marginal increase in the cash-flow volatility of dirty firm type σ_D or a marginal reduction in their expected cash flow $\overline{X}_D$*

1. *increases e^*_D;*

2. *has no effect on e^*_C when clean is marginal (Region 3) and decreases e^*_C when both types are fully funded (Region 4).*

Intuitively, higher cash-flow volatility increases the put value associated with the dirty type and, hence, raises the marginal social cost of funding dirty projects. For reductions

[12] Since $\overline{X}_D$ is increasing in volatility, this means that we compensate μ_D so that $\overline{X}_D$ remains constant.

in $\overline{X}_D$, this effect on the put value is also at play, and, from the regulator's perspective, is reinforced by the reduction in NPV. In either case, the regulator optimally responds by increasing capital requirements for dirty projects.[13]

Part 2 of Proposition 4 investigates the spillover effects of climate-related risks that affect only dirty firms on the capital requirements for clean firms. In the region where clean firms are the marginal type, clean capital requirements are optimally set to maximize the PPI, $e_C^* = \underline{e}_C^{PPI}$, so optimal prudential capital requirements for clean firms remain unaffected. However, in the region where both types are fully funded (Region 4), the optimal balancing of marginal puts (Principle P4) requires that capital requirements for clean firms are adjusted downward.

In sum, the optimal regulatory response to climate-related risks can be implemented with a brown penalizing factor for dirty firms (relative to the prudential baseline without climate risk) and, in some instances, a green supporting factor. As before, the exact calibration of these adjustments depends on the capitalization of the banking sector, as characterized by Proposition 3. This optimal regulatory response has the following allocative consequences.

Corollary 1 (Real Effects of Optimal Marginal Policy Adjustments) *The optimal policy response to an increase in the cash-flow volatility of the dirty firms σ_D and/or a reduction in their expected cash flow $\overline{X}_D$*

1. *crowds out lending to dirty firms if bank equity is low, $E < E_1$;*

2. *crowds out lending to clean firms if bank equity is intermediate $E \in (E_2, E_3)$.*

The second part of the corollary states that, perhaps surprisingly, small transition risks can make it optimal for a prudential regulator to sacrifice lending to clean firms. To see why this is the case, recall that a prudential regulator only cares about climate-related risks through their effect on firm cash flows and, in turn, financial stability in the

[13] In Region 2, this prediction holds weakly, in the sense that capital requirements. for dirty projects remain constant.

banking sector. As long as these effects are small in magnitude, the prudential regulator still prefers the dirty type and therefore finds it optimal, at the margin, to allow the rationing of clean lending in the name of financial stability.

This conclusion changes for sufficiently large changes in relative prospects of clean and dirty types, which result in a more drastic change in optimal prudential policy, even under a purely prudential regulatory objective.

Proposition 5 (Policy Adjustments in Response to Large Transition Risks) *A sufficiently large decrease in the expected cash-flow of dirty firms $\overline{X}_D$, or a sufficiently large increase in their cash-flow volatility σ_D, lead to a switch in the regulator's preferred type to clean. Clean types are funded first so that their funding is increased.*

Intuitively, once climate-related effects on relative cash flows are sufficiently large, clean firms deliver the highest PPI. This leads to a discrete (rather than marginal) change in optimal prudential capital requirements. Prudential capital requirements are then set in such a way that bankers' ranking adjusts accordingly. In analogy to the regions illustrated in Figure 4, clean firms are funded first (in regions 1 and 2), and dirty firms receive funding only after clean lending opportunities have been exhausted (regions 3 and 4).

In summary, the presence of transition risks that lower the prospects of dirty firms relative to clean firms rationalizes the use of the ad-hoc policy tools we analyzed in Section 3. In particular, brown penalizing and green supporting factors become part of the prudential toolkit, and their magnitudes are directly linked to the magnitude of the effect of climate risk on relative cash flow prospects of clean and dirty firms.

4.3 The Effect of Consumption Externalities

We now consider climate-related risks that are endogenous to the funding decisions of the financial sector and, hence, bank regulation. We initially consider externalities that are not reflected in the cash flows of bank-funded firms. These could be pure consumption externalities (e.g., carbon emissions directly affect the utility of agents in the economy), or they could reflect effects on cash flows outside of the bank regulator's jurisdiction (e.g., floods in Bangladesh may have limited effects on the cash flows of firms funded by European banks). Because the prudential regulator's objective function (9) does not account for these consumption externalities, we readily obtain

Observation 1 *The optimal prudential policy is unaffected by consumption externalities, regardless of their size.*

Taken together with the findings from the previous section, this observation implies that, even in the presence of substantial consumption externalities and moderate transition risk, a prudential regulator may find it optimal to tolerate the crowding out of clean lending, in order to be able to fund an unchanged number of dirty firms at higher capital requirements.

Because mitigating carbon externalities has become an important global policy objective, it is natural to also consider a broader mandate for financial regulators that explicitly accounts for carbon externalities, in addition to the usual prudential objective.[14] We will refer to this broader objective function as a "green mandate" and the associated regulator as a "green regulator". Assuming, for simplicity, that the negative externality caused by dirty firms is linear in the mass of dirty firms that obtain financing (or, equivalently, linear in carbon emissions), the green regulator's objective function is

$$\max_{\underline{\mathbf{e}}} \Omega_G = \max_{\underline{\mathbf{e}}} \sum \omega_q \left(\underline{\mathbf{e}}\right) \left[\mathrm{NPV}_q - \phi_q - \lambda \cdot \mathrm{PUT}_q(\underline{e}_q)\right]. \tag{16}$$

In analogy to the PPI, we can then define the green regulator's social profitability index,

[14] In fact, the ECB's secondary mandate is to support economic policy in the eurozone. To the extent that a reduction in carbon emissions is part of general economic policy, this broader objective function would therefore seem to be within the scope of the ECB's mandate.

which captures "bang for buck" including associated carbon externalities ϕ_q,

$$\mathrm{SPI}(\underline{e}_q) = \frac{\mathrm{NPV}_q - \phi_q - \lambda \cdot \mathrm{PUT}_q(\underline{e}_q)}{I\underline{e}_q}. \tag{17}$$

The green regulator's preferred type is the one that achieves the maximal SPI (not maximal PPI). Hence, small carbon externalities ϕ_D do not lead to a change the regulator's preferred type relative to the prudential regulator. Therefore, the characterization of optimal capital requirements is very similar to the prudential regulator's case under moderate transition risk. The most interesting and novel case is the one where externalities large enough, so that the SPI becomes negative for dirty firm, so that the green regulator prefers the clean type:

Assumption 1 *$\phi_D > NPV_D$.*

Under this assumption, carbon emissions are so significant that funding dirty firms reduces social welfare, even when capital requirements for dirty loans are (optimally) set to 100%, i.e., $\mathrm{SPI}_D(1) = \frac{\mathrm{NPV}_D - \phi_D}{I} < 0$. However, banks still find it privately profitable to finance dirty types, even at a 100% capital requirement, because $r_D^{\max}(1) = \frac{\mathrm{NPV}_D}{I} > 0$.

Observation 2 *Even under maximum capital requirements of 100%, the financing of dirty firms is financially profitable for banks.*

This observation illustrates the limited power of capital requirements to address consumption externalities. Distortions generated by the deposit-insurance put can always be dealt with using capital requirements. In particular, if a firm generates negative prudential value for all levels of $\underline{e}_q$,[15] the prudential regulator can always deter banks from funding such a type by imposing sufficiently high capital requirements. This is not the case in the presence of consumption externalities, because, even at capital requirements of 100%, dirty firms with negative social value can attract funding, since

[15] Since the deposit insurance put can always be fully eliminated with a capital requirement of 100%, this is the case if and only if $\mathrm{NPV}_q < 0$, since $\mathrm{PPI}_q(1) = \mathrm{NPV}_q/I$.

$$r_D^{\max}(1) = \frac{\text{NPV}_D}{I} > 0 > \frac{\text{NPV}_D - \phi_D}{I} = \text{SPI}_D(1). \tag{18}$$

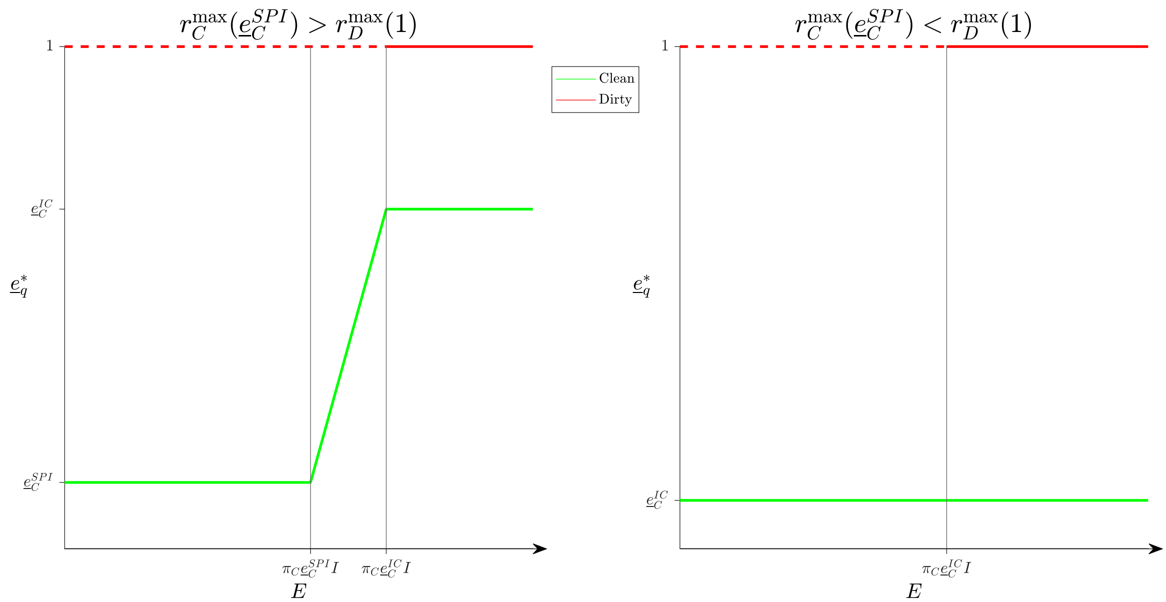


Figure 5. Capital regulation under green mandate. This figure plots optimal green capital requirements depending on the relevance of the bankers' IC constraint. In the left panel, it is initially possible to set $\underline{e}_C^* = \underline{e}_C^{SPI}$ and banks can be incentivized to lend to clean firms by setting capital requirements for dirty firms to 1. In the right panel, bankers' must be additionally incentivized via a reduction in clean capital requirements as to prevent financing of dirty firms.

The fact that funding dirty projects is profitable even at a capital requirement of 100% constrains the green regulator's optimal policy. To see this, let us first consider the case $r_C^{\max}\left(\underline{e}_C^{SPI}\right) > r_D^{\max}(1)$, as illustrated in the left panel of Figure 5. In this case, the regulator can set the capital requirement for clean loans to maximize their SPI and ensure that clean loans are funded first by setting the capital requirement for dirty loans to 100%. For small values of aggregate bank equity (region 1), $E \leq \pi_C \underline{e}_C^{SPI} I$, only clean firms are funded with the clean capital requirement optimally set to $\underline{e}_C^{SPI}$. Once all clean firms have been funded (region 2), the regulator then raises the capital requirements for clean types to avoid that additional equity is used to fund dirty firms and to lower the deposit-insurance put for clean loans. This increase of clean capital requirement is optimal up to the point at which banks are indifferent between funding clean and dirty loans, $r_C^{\max}\left(\underline{e}_C^{IC}\right) = r_D^{\max}(1)$. If the regulator raised capital requirements for clean projects beyond $\underline{e}_C^{IC}$, banks would prefer to fund dirty rather than clean funding, which explains why capital requirements on clean firms are initially capped at $\underline{e}_C^{IC}$. As a result, once aggregate bank equity exceeds the amount required to finance all clean firms at a capital requirement of $\underline{e}_C^{IC}$, $E > \pi_C \underline{e}_C^{IC} I$, banks start to finance dirty firms at $e_D^* = 1$ (as indicated by the solid region for e_D^*), revealing that the regulator is eventually powerless to deter dirty funding.[16]

In the second case, $r_C^{\max}\left(\underline{e}_C^{SPI}\right) < r_D^{\max}(1)$, the regulator cannot set the capital requirements for cleans loans to the level that maximizes the SPI, because banks would then prefer to fund dirty loans. For low levels of bank equity (region 1), the green regulator is therefore forced to lower capital requirements below $\underline{e}_C^{SPI}$ in order to ensure that $r_C^{\max}\left(\underline{e}_C^{IC}\right) = r_D^{\max}(1)$. Intuitively, it is not possible to induce banks to make clean loans by raising the capital requirement for dirty loans. Therefore, the regulator also has to subsidize clean loans by lowering their capital requirements below the level that would maximize the SPI, up to the point where banks are willing to fund clean loans.[17] As before, once aggregate bank equity exceeds the amount required to finance all clean firms at a capital requirement of $\underline{e}_C^{IC}$, $E > \pi_C \underline{e}_C^{IC} I$, the regulator is powerless to prevent the funding of dirty firms.

In sum, consumption externalities that materialize outside of the banking sector are not accounted for by the prudential mandate. A broader mandate would be required to account for such externalities. However, our analysis suggests that capital requirements are not the most natural tool to address these externalities: Even at maximal requirements, banks may find dirty loans still financially profitable. This potentially severe wedge between welfare and bankers' profit motive may require the green regulator to

[16] For very high levels of equity, e.g., $E = I$, (outside of the plotted region in Figure 5), it is again optimal to equalize marginal puts under full funding for both types, as in Region 4 of Figure 4.

[17] Clearly, for this course of action to be optimal, it also has to be the case that $\frac{\text{NPV}_C - \lambda \cdot \text{PUT}_C(\underline{e}_C^{IC})}{\underline{e}_C^{IC}} > \frac{\text{NPV}_D - \phi_D}{I}$, which we assume in the figure.

make significant sacrifices with respect to financial stability in order to promote clean lending and deter dirty lending.

Such trade-offs between financial stability and negative consumption externalities would not arise if Pigouvian taxes are available to the regulator: These would ensure that the externalities (through Pigouvian taxation) are directly reflected in the bankers' maximal ROE, rendering projects with negative SPI also unprofitable from a private perspective. We, thus, conclude that capital requirements are a second-best tool to address broader climate externalities.

5 Conclusion

This paper provides a flexible modeling framework to analyze the green capital requirements. Such a framework is needed because central banks and bank regulators around the world are grappling with the question of whether to adjust capital requirements to reflect carbon emissions.

Our analysis has two major takeaways. First, from a positive perspective, it clarifies that the most commonly suggested policy tools, the brown penalizing and green supporting factors, are not equivalent and have potentially subtle effects. Second, from a normative perspective, we characterize how optimal capital requirements depend on the regulatory objective (a prudential or a broader green mandate) and the nature of climate-related risks. While climate-related risks that affect bank stability can be optimally addressed by a combination of green supporting and brown penalizing factors, capital regulation is a less effective tool to address carbon externalities that manifest itself outside of the banking sector.

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