Banks, Markets, and the Color of Finance

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Keywords: Bank capital, Climate finance, Financial system, Financial stability

JEL Classifications: G10, G21, G28

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September 16, 2023

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1 Introduction

There has been much concern about how climate change may threaten financial stability (Giglio et al. (2021), Hong et al. (2020), Stroebel and Wurgler (2021)). This has spurred discussions on how the banking system can facilitate the transition of the economy to one with more environmentally friendly ("green") investments. One proposal is to lower bank capital requirements on green loans, making them more attractive to banks than loans to carbon-emission-oriented ("brown") firms (Dombrovskis (2017)). Boot and Schoenmaker (2018) criticize this approach because lowering capital requirements on green loans would sacrifice financial stability; they suggest increasing capital requirements on brown loans.

The Boot-Schoenmaker proposal reflects the intuitive idea that increasing capital requirements on brown loans makes them less attractive for banks, thus discouraging brown investments without reducing bank capital ratios and jeopardizing stability. Carney (2015), however, cautions against this: "Some have suggested we ought to accelerate the financing of a low carbon economy by adjusting the capital regime for banks and insurers. That is flawed. History shows the danger of attempting to use such changes in prudential rules – designed to protect financial stability – for other ends."

This debate raises an important question: should capital requirements on brown loans be increased when green investments have higher social benefits? Our answer is: perhaps not. Bank regulators may be unable to have their cake and eat it too – increasing capital requirements on brown loans, even without decreasing them on green loans, may also *increase* bank risk. We derive this result with a model in which brown and green firms compete within a sector. Think of gasoline-powered carmakers competing with electric vehicle producers in the automobile sector. Investment by a firm's competitor increases the probability that the firm's own investment will be prematurely liquidated. Firms need financing and may borrow from banks or the capital market. Firms are observationally identical within a sector but unobservably heterogeneous, with good and bad credits in the cross-section. Banks can screen borrowers at a cost to weed out bad investments. In contrast, there is no credit screening in the capital market.[1] Higher bank capital incentivizes more screening but capital is costly. There is a fixed aggregate bank capital supply, and the capital cost is endogenously determined.

[1] The notion that banks are screening specialists which distinguishes them from the market is familiar from foundational theories of financial intermediation (Allen (1990), Ramakrishnan and Thakor (1984)).

We characterize the laissez-faire without capital requirements. Banks choose their privately-optimal capital, with its cost determined in general equilibrium. High-quality (large) firms obtain market finance, intermediate-quality (mid-sized) firms take bank loans, and the riskiest (small) firms are rationed.

We then examine effects of a minimum capital requirement on brown loans. As the requirement increases the bank capital cost via a general equilibrium effect – higher capital demand by banks subject to the requirement – more small brown firms *as well as* small green firms are denied credit. At the high end of the quality (size) spectrum, the requirement induces large brown firms to switch from banks to market finance. The lack of credit screening in the market results in more projects of these *migrating* brown firms being funded. This intensifies competition faced by bank-funded large green firms operating in the same sectors as those brown firms, which increases the odds of their green investments (and hence loans for these investments) being prematurely terminated. Since premature loan termination erodes bank capital, banks funding these green firms keep less capital and hence reduce screening, leading to higher bank risk. The analysis thus shows that due to the ability of large brown firms to switch from banks to the market, capital requirements have two unintended consequences: (i) aggregate investments by large brown firms *increase* (intensive-margin effect); and (ii) this feeds back to banking by intensifying competition faced by large bank-funded green firms. Ironically, capital requirements may lead to *more* total pollution and *higher* bank risk. We discuss consequent policy implications.

We contribute to the climate finance literature that Giglio et al. (2021) review. Acharya et al. (2023) assess regulators' climate-stress-test scenarios. Empirics show banks price in climate risk (Ivanov et al. (2022), Nguyen et al. (2022)). Recent theories study consequences of bank regulations to facilitate green transition. Oehmke and Opp (2022) show when there is capital scarcity, raising capital requirements on brown loans is a limited regulatory option. So, capital requirements on green loans may be lowered, which elevates bank risk. Our paper differs. First, we do not rely on the regulator's inability to raise capital requirements on brown loans. Rather, we focus on how capital requirements induce bank-to-market exit of brown firms. Second, we examine how this exit feeds back to banking to affect *bank-funded* green firms, impairing stability even when capital requirements on green loans are *not* lowered. These lead to different policy implications in the two papers.

Empirics also highlight other unintended consequences of climate policies. Giannetti et al. (2023) document that European banks portraying themselves as environmentally conscious extend more credit to brown industries, and this is more pronounced for lower-capital banks. Kacperczyk and Peydró (2022) find that banks committing to decarbonization reduce lending to brown firms, but there is no improvement in firms' environmental performance.

Our paper relates to studies on the firm's choice of bank versus market finance (Allen and Gale (1997, 1999, 2000), Bolton and Freixas (2000), Boot and Thakor (1997), Holmstrom and Tirole (1997), Song and Thakor (2010)). The literature on bank capital requirements is also relevant (Allen et al. (2015, 2011), Mehran and Thakor (2011), Morrison and White (2005), Thakor (2014)).

2 Model

Setting: Consider a two-date, $t \in \{0, 1\}$, economy with risk neutrality and no discounting. There are brown and green industries. Firms in the two industries make competing products. In both industries, a firm has a project that needs a \$1 investment at $t = 0$. The project may be good or bad. The date-1 payoff is $X > 1$ for a good project, and 0 for a bad project. No one, including the firm, knows the type of its project *a priori*. This precludes signaling which is unimportant here.

Each firm, brown or green, belongs to a sector indexed by λ. A sector is defined by product functionality satisfying a set of consumer needs. For instance, automobile is a sector, and products in this sector meet consumers' transportation needs. This sector has brown firms (gasoline carmakers) and green firms (electric carmakers). The date-0 common knowledge is that the project of a firm of any color in sector λ is good with probability λ and bad with probability $1 - \lambda$. λ distributes on support $[0, 1]$ with a continuous density $f(\lambda)$ for both industries. The mass of firms in each industry is $\int_0^1 f(\lambda) d\lambda = 1$ across all sectors. The total firm mass is thus 2.

Brown and green firms in a given sector compete. Competition is sector-confined: no firm in sector λ_1 competes with a firm in sector $\lambda_2 \neq \lambda_1$. For example, automobile firms do not compete with food companies. Since our focus is on the impact of competition between brown and green firms, we take as fixed the degree of competition among same-color firms in a sector, so this competition plays no role. Our results are qualitatively unaffected by such competition, but it adds complexity.[2]

[2]We focus on competition between say Tesla and Ford (different color), not that between GM and Ford (same color).

Our modeling of λ as both the sector and the probability of a good investment in that sector is for modeling parsimony, but it does have a natural interpretation. Sectors differ in the likelihood of individual firm success due to the nature of the business. A regulated utility with an electricity-generation plant is innately less failure prone (higher λ) than say a new electric-vehicle manufacturer, despite both being green. Thus, the cross-sector heterogeneity in success probabilities leads naturally to an association between a sector and the probability of a good investment in that sector.

For a firm of color $i \in \{\text{brown}, \text{green}\}$ in sector λ, if the probability that a firm of color $j \in \{\text{brown}, \text{green}\}$, where $i \neq j$, in the same sector λ is funded is $\gamma(\lambda)$, then firm i's good project will be terminated before $t = 1$ with probability $\alpha\gamma(\lambda)$, where $\alpha \in (0, 1)$ is a scaling factor. A larger α indicates greater competition between brown and green firms, and $\gamma(\lambda)$ is determined in the analysis. The competition has no impact on a bad project, which always returns nothing. We model consequences of the (competition-induced) premature termination later. To understand this specification, consider sector λ. There is an $f(\lambda)$ mass of green firms, and an $f(\lambda)$ mass of brown firms. If a brown firm's project is funded with probability $\gamma(\lambda)$, then the mass of funded brown projects is $\gamma(\lambda)f(\lambda)$. The impact on an average sector-λ green firm is $\frac{\gamma(\lambda)f(\lambda)}{f(\lambda)} = \gamma(\lambda)$.

Why is a firm's project termination affected by its competitor's funding? Examples abound. When electric-truck maker Nikola made its SPAC debut, it created enormous investor excitement about its technology – investors did not realize the technology was non-existent. This optimism about a non-existent new technology led to excessive pessimism about traditional gasoline-powered vehicles. Funding to good manufacturers of gasoline-powered vehicles thus declined. Another example is in the defense sector. When the Berlin Wall fell, the whole defense sector faced a downturn, so all firms needed to cut investments. If any firm increased investment, it would put downward pressure on all profit margins.[3]

Pollution: A brown firm's project, good or bad, generates a social loss of ω (call it "pollution") if funded; ω is internalized only by regulators but not others. Other than that, brown and green firms are modeled with the same project payoffs and firm distributions $f(\lambda)$ over sectors, and equal mass. This symmetry is chosen to delineate the effects of capital requirements on brown loans, ensuring the results are *not* driven by exogenous differences between brown and green firms along those dimensions.

[3]William Anders, then CEO of General Dynamics, urged all defense contractors to cut back on capital expenditures.

Financing: Firms seek funding from banks or the capital market. Bank funding is supplied with uninsured deposits $1-k$ (with a gross deposit rate r_D) and equity k (with an expected gross return $r_E > 1$, capturing the bank capital cost). There is a limited (exogenous) aggregate bank capital supply K. We endogenize k and r_E. The deposit market is competitive, so r_D ensures that depositors earn an expected gross return of 1. The banking sector is also competitive, so banks maximize borrower surplus. Call banks funding brown (*resp.* green) firms "brown (*resp.* green) banks." For a firm seeking market finance, investors provide the \$1 funding via debt, charging a gross interest rate r_M. The debt market is also competitive, so all surplus goes to firms.

Bank screening reduces type-2 errors.[4] A bank can perfectly identify a good project, but it identifies a bad project only with probability $\theta \in [0,1]$, which is the bank's privately-chosen screening precision, with a corresponding cost $\frac{\theta^2}{2}$. There is no screening in market finance. The assumption that the firm does not know its own project type but the bank can discover this via credit analysis captures the idea that assessing investment prospects may require an interpretation of broad industry conditions that the bank may be better at than the firm.

When a good project is terminated due to competition, it is liquidated before $t=1$, with a liquidation value of \$1. In the case of bank finance, part of the liquidation value, $1-k$, is returned to depositors, but the bank only recovers a fraction $1-\delta$ (with $\delta \in (0,1]$) of the remaining k, i.e., $(1-\delta)k$. For market finance, investors receive the entire \$1 liquidation value. We have assumed that part of the bank's equity k is eroded upon premature loan liquidation,[5] which makes liquidation dissipatively costly for the bank and affects how much equity it raises.

Liquidation is observable and contractable – the date-0 deposit contract stipulates the bank will return $1-k$ (deposit amount) to depositors upon the interim liquidation. Similarly, the date-0 debt contract with market finance stipulates the firm will return \$1 (debt amount) to investors. We can model a less-than-\$1 liquidation value, and also let financiers receive less than the funding they provided upon liquidation (i.e., depositors receive less than $1-k$, and market investors receive less than \$1). The current specification merely helps simplify derivations of r_D and r_M.

[4] Modeling screening to reduce both type-1 and type-2 errors complicates the algebra, with qualitatively similar results. Our specification that screening reduces type-2 errors is consistent with the idea that it is typically easier for credit analysis to identify good projects than to weed out bad ones that are observationally identical to good projects in many dimensions.

[5] When a bank has to prematurely terminate a loan, it typically will need to write down the loan value, and hence its book-equity value.

Timeline: The events between dates 0 and 1 unfold as follows:

- Each firm, brown or green, decides whether to approach a bank or the market for funding.
- If approached by a firm, a bank raises equity k, screens the firm's project by privately choosing its screening precision θ, and makes its acceptance/rejection decision. Since a rejected borrower is believed to have a bad project for sure, it cannot get financing elsewhere.
- If the bank accepts the borrower, it raises uninsured deposits $1-k$, and lends $k+(1-k)=1$, specifying a loan repayment L (which is also the gross loan rate, given the $1 loan size). Depositors demand a gross rate r_D, based on their updated beliefs about the type of the funded project.
- If a firm approaches the market, investors demand a gross rate r_M for the debt.
- If competition forces a good project to be terminated, its liquidation value is distributed between the bank and depositors (for bank finance) or returned to investors (for market finance).
- Project types become public. Agents get paid.

3 Laissez-Faire

In a laissez-faire benchmark without capital requirements, banks choose privately-optimal capital. We first take the bank capital cost, $r_E > 1$, as given, and examine privately-optimal bank capital and screening, and firms' financing choices. Lastly, we characterize r_E.

Bank Finance: Suppose a sector-λ firm of any color approaches a bank. We use backward induction, beginning with the bank's choice of θ for a given capital amount k, deposit rate r_D, and loan rate L. The bank chooses θ to maximize its expected net profit:

$$\lambda[1-\alpha\tilde{\gamma}(\lambda)][L-r_D(1-k)]+\lambda\alpha\tilde{\gamma}(\lambda)(1-\delta)k+(1-\lambda)\theta k+(1-\lambda)(1-\theta)(0)-r_Ek-\frac{\theta^2}{2}. \quad (1)$$

The first term is bank profit when a good project survives competition – it receives the loan repayment L and pays depositors $r_D(1-k)$; this occurs with probability $\lambda[1-\alpha\tilde{\gamma}(\lambda)]$, where $\tilde{\gamma}(\lambda)$ is the probability that a different-color, sector-λ firm is funded. With probability $\lambda\alpha\tilde{\gamma}(\lambda)$ a good project is prematurely liquidated due to competition and the bank recovers $(1-\delta)k$ (second term). If the bank weeds out a bad project (with probability $(1-\lambda)\theta$), it retains capital k instead of lending and losing it (third term).

If a bad project is not screened out (with probability $(1-\lambda)(1-\theta)$), it lends and loses k (fourth term). The fifth term is the cost of raising k. The last term is the screening cost.

The solution is

$$\theta = (1-\lambda)k. \tag{2}$$

Higher capital k implies the bank has more to lose upon funding a bad project, so screening investment θ increases. As shown later, competition affects k, and hence *indirectly* affects θ via (2).

The depositors' participation constraint is

$$\frac{\lambda[1-\alpha\tilde{\gamma}(\lambda)]}{\lambda+(1-\lambda)(1-\theta)} r_D(1-k) + \frac{\lambda\alpha\tilde{\gamma}(\lambda)}{\lambda+(1-\lambda)(1-\theta)}(1-k) \geq 1-k \quad \Rightarrow \quad r_D \geq 1 + \frac{(1-\lambda)(1-\theta)}{\lambda[1-\alpha\tilde{\gamma}(\lambda)]}. \tag{3}$$

The bank lends with probability $\lambda+(1-\lambda)(1-\theta)$, conditional on which: (i) with probability $\lambda[1-\alpha\tilde{\gamma}(\lambda)]$ the funded project is good and survives competition, so depositors receive $r_D(1-k)$; (ii) with probability $\lambda\alpha\tilde{\gamma}(\lambda)$ the project is good but is prematurely liquidated due to competition, so depositors obtain $1-k$; and (iii) with the remaining probability $(1-\lambda)(1-\theta)$ the project is bad, and depositors get nothing.

A sector-λ firm seeking bank finance will be funded with probability $\gamma(\lambda) = \lambda + (1-\lambda)(1-\theta)$, with θ solving the bank's problem:

$$\max_{k,\theta,L} \; \pi_{\text{bank}} \equiv \lambda[1-\alpha\tilde{\gamma}(\lambda)](X-L) \tag{4}$$

$$\text{s.t. } \lambda[1-\alpha\tilde{\gamma}(\lambda)][L-r_D(1-k)] + [\lambda\alpha\tilde{\gamma}(\lambda)(1-\delta)+(1-\lambda)\theta]k - r_E k - \frac{\theta^2}{2} \geq 0 \tag{5}$$

$$0 \leq k \leq 1 \tag{6}$$

and (2), (3).

The bank chooses k, θ and L to maximize borrower surplus, $\pi_{\text{bank}} \equiv \lambda[1-\alpha\tilde{\gamma}(\lambda)](X-L)$. The absence of type-1 screening errors means a good project is always funded, but the borrower earns a profit $X-L$ only if the project survives competition; this occurs with probability $\lambda[1-\alpha\tilde{\gamma}(\lambda)]$. The borrower gets nothing with a bad project (even if funded). The bank faces its own incentive-compatibility constraint for screening (2) and participation constraint (5), the depositors' participation constraint (3), and the constraint on the capital amount (6).

Lemma 1. *For a sector-λ firm of any color seeking bank finance, if a different-color firm in sector λ (competitor) is funded with probability $\tilde{\gamma}(\lambda)$, then the firm is funded by its own bank with probability*

$$\gamma(\lambda) = r_E - (1-\lambda)^2 + \lambda\alpha\delta\tilde{\gamma}(\lambda). \tag{7}$$

Proof. In equilibrium, (3) and (5) bind: $r_D = 1+\frac{(1-\lambda)(1-\theta)}{\lambda[1-\alpha\tilde{\gamma}(\lambda)]}$, $L-r_D(1-k) = \frac{r_E k+\frac{\theta^2}{2}-[\lambda\alpha\tilde{\gamma}(\lambda)(1-\delta)+(1-\lambda)\theta]k}{\lambda[1-\alpha\tilde{\gamma}(\lambda)]}$. Using (2), we rewrite (4) as

$$\min_{k\in[0,1]} L = \frac{\frac{(1-\lambda)^2}{2}k^2 + [r_E - 1 + \lambda\alpha\delta\tilde{\gamma}(\lambda) - (1-\lambda)^2]k + 1 - \lambda\alpha\tilde{\gamma}(\lambda)}{\lambda[1-\alpha\tilde{\gamma}(\lambda)]}. \tag{8}$$

Denote the solution as $k(\lambda)$. Since $\frac{\partial^2 L}{\partial k^2} > 0$ and $\frac{\partial L}{\partial k}|_{k=1} > 0$, $k(\lambda) < 1$. Suppose $\frac{\partial L}{\partial k}|_{k=0} < 0$ (which, as shown in the proof of Proposition 1, requires λ to be below a cutoff λ_{mkt}), so $k(\lambda) > 0$ (the outcome $k(\lambda) = 0$ corresponds to market finance). Thus, the first-order condition (FOC), $\frac{\partial L}{\partial k} = 0$, yields

$$k(\lambda) = 1 - \frac{r_E - 1 + \lambda\alpha\delta\tilde{\gamma}(\lambda)}{(1-\lambda)^2}. \tag{9}$$

Substituting (9) into (2), $\theta = 1 - \lambda - \frac{r_E - 1 + \lambda\alpha\delta\tilde{\gamma}(\lambda)}{1-\lambda}$. Since $\gamma(\lambda) = \lambda + (1-\lambda)(1-\theta)$, (7) follows. ■

When it is easier for a competitor to obtain funding (higher $\tilde{\gamma}(\lambda)$), the firm is also more likely to be funded by its own bank (higher $\gamma(\lambda)$). Competitor funding causes the firm's good project more likely to be prematurely terminated, increasing the odds of capital loss for the firm's bank. The bank thus raises less capital. The consequent screening reduction (see (2)) increases the bank's odds of funding a bad project, increasing $\gamma(\lambda)$. When competition is greater (higher α) or capital erosion upon premature loan liquidation is bigger (higher δ), the adverse competitive impact on screening intensifies, increasing $\gamma(\lambda)$. A higher r_E also lowers bank capital, increasing $\gamma(\lambda)$.

Market Finance: There is no screening in the market, so a sector-λ firm seeking market finance always gets funded, with the gross debt rate r_M satisfying

$$\lambda(1-\alpha)r_M + \lambda\alpha(1) + (1-\lambda)(0) \geq 1 \quad \Rightarrow \quad r_M \geq \frac{1-\lambda\alpha}{\lambda(1-\alpha)}. \tag{10}$$

Due to the symmetry in the benchmark, if a firm chooses market finance, so does its competitor and thus is always funded ($\tilde{\gamma}(\lambda) = 1$). So, the probability is $\lambda\alpha\tilde{\gamma}(\lambda) = \lambda\alpha$ that a firm's good project is terminated, and investors receive \$1. With probability $\lambda(1-\alpha)$ a firm's good project survives competition, and investors obtain r_M. With probability $1-\lambda$ the project is bad, and investors get nothing. Constraint (10) binds in equilibrium, so a firm's expected surplus from market finance is

$$\pi_{\text{mkt}} = \lambda(1-\alpha)(X - r_M) = \lambda(1-\alpha)X - (1-\lambda\alpha). \tag{11}$$

Proposition 1 (Laissez-Faire)**.** *Given the bank capital cost $r_E > 1$, a sector-λ firm of any color chooses its funding source as follows:*

1. *If $\lambda \geq \lambda_{\text{mkt}}$, where*

$$\lambda_{\text{mkt}} = \frac{(2+\alpha\delta) - \sqrt{(2+\alpha\delta)^2 - (8-4r_E)}}{2}, \tag{12}$$

the firm borrows from the market, with the debt gross rate r_M given by (10).

2. *If $\lambda \in (\lambda_{\text{bank}}, \lambda_{\text{mkt}})$, where λ_{bank} is uniquely determined by*

$$\frac{(1-\alpha\delta\lambda_{\text{bank}}) - \alpha\lambda_{\text{bank}}\left[r_E - (1-\lambda_{\text{bank}})^2\right] - \frac{\left(1-\lambda_{\text{bank}} - \frac{r_E - 1 + \alpha\delta\lambda_{\text{bank}}}{1-\lambda_{\text{bank}}}\right)^2}{2(1-\alpha\delta\lambda_{\text{bank}})}}{\lambda_{\text{bank}}(1-\alpha\delta\lambda_{\text{bank}}) - \alpha\lambda_{\text{bank}}\left[r_E - (1-\lambda_{\text{bank}})^2\right]} = X, \tag{13}$$

the firm seeks a bank loan. The bank raises capital

$$k(\lambda) = \frac{(1-\lambda)^2 - (r_E - 1 + \lambda\alpha\delta)}{(1-\lambda)^2(1-\lambda\alpha\delta)} \in (0,1), \tag{14}$$

which is decreasing in λ, α, δ, and r_E. The loan is approved with probability

$$\gamma(\lambda) = \frac{r_E - (1-\lambda)^2}{1-\lambda\alpha\delta}, \tag{15}$$

which is increasing in λ, α, δ, and r_E.

3. *If $\lambda \leq \lambda_{\text{bank}}$, the firm cannot obtain funding. When r_E rises, λ_{mkt} falls while λ_{bank} increases.*

Proof. From (8), $\frac{\partial^2 L}{\partial k^2} > 0$. If $\frac{\partial L}{\partial k}|_{k=0} = \frac{r_E - 1 + \lambda\alpha\delta\tilde{\gamma}(\lambda) - (1-\lambda)^2}{\lambda[1-\alpha\tilde{\gamma}(\lambda)]} \geq 0$, i.e., $r_E - 1 + \lambda\alpha\delta\tilde{\gamma}(\lambda) - (1-\lambda)^2 \geq 0$, the optimal solution for k is $k(\lambda) = 0$. This corresponds to market finance: the entire \$1 is debt financed. Again, if a firm chooses market finance, so does its competitor, hence $\tilde{\gamma}(\lambda) = 1$. The condition for market finance thus becomes $r_E - 1 + \lambda\alpha\delta - (1-\lambda)^2 \geq 0$, i.e., $\lambda \geq \lambda_{\text{mkt}}$, where $r_E - 1 + \lambda_{\text{mkt}}\alpha\delta - (1-\lambda_{\text{mkt}})^2 = 0$. The solution for λ_{mkt} is in (12): clearly $\frac{\partial \lambda_{\text{mkt}}}{\partial r_E} < 0$.

For $0 \leq \lambda < \lambda_{\text{mkt}}$, $\frac{\partial L}{\partial k}|_{k=0} < 0$. Since $\frac{\partial L}{\partial k}|_{k=1} > 0$, the optimal solution for k in (9) is given by $\frac{\partial L}{\partial k} = 0$. Due to the symmetry in the benchmark, if a firm seeks bank finance, so does its competitor, hence $\tilde{\gamma}(\lambda) = \gamma(\lambda)$. Substituting this into (7), we have $\gamma(\lambda) = r_E - (1-\lambda)^2 + \lambda\alpha\delta\gamma(\lambda)$, yielding (15). Substituting (15) into (9) (letting $\tilde{\gamma}(\lambda) = \gamma(\lambda)$) yields (14). The comparative statics of $k(\lambda)$ and $\gamma(\lambda)$ with respect to λ, α, δ and r_E follow readily.

Lastly, we determine λ_{bank}. We show a sector-λ firm makes a positive expected profit from bank finance ($\pi_{\text{bank}} > 0$) only if $\lambda > \lambda_{\text{bank}}$, i.e., $L < X$ for $\lambda > \lambda_{\text{bank}}$, while $L \geq X$ for $\lambda \leq \lambda_{\text{bank}}$. Applying the Envelope Theorem to (8), we can show the value function L decreases with λ, while it increases with r_E.[6] Substituting the respective expressions for $k(\lambda)$ and $\gamma(\lambda)$ in (14) and (15) into the expression for L in (8), we have $L = \frac{(1-\alpha\delta\lambda) - \alpha\lambda[r_E - (1-\lambda)^2] - \frac{1}{2(1-\alpha\delta\lambda)}\left(1 - \lambda - \frac{r_E - 1 + \alpha\delta\lambda}{1-\lambda}\right)^2}{\lambda(1-\alpha\delta\lambda) - \alpha\lambda[r_E - (1-\lambda)^2]}$. Since $\frac{\partial L}{\partial \lambda} < 0$ and $L \uparrow \infty$ when $\lambda \downarrow 0$, there exists a unique λ_{bank}, determined by (13). Since $\frac{\partial L}{\partial r_E} > 0$ and $\frac{\partial L}{\partial \lambda} < 0$, $\frac{\partial \lambda_{\text{bank}}}{\partial r_E} > 0$ by the Implicit Function Theorem. ■

The result that the least risky firms ($\lambda \geq \lambda_{\text{mkt}}$) go to the market, riskier firms ($\lambda \in (\lambda_{\text{bank}}, \lambda_{\text{mkt}})$) choose banks, and the riskiest firms ($\lambda \leq \lambda_{\text{bank}}$) are rationed echoes Boot and Thakor (1997) and Holmstrom and Tirole (1997). By the documented negative relation between firm risk and size (Mata and Portugal (1994)) – smaller firms are *ceteris paribus* riskier – this implies the largest firms are market financed, mid-sized firms are bank funded, and the smallest firms are rationed.

Despite this similarity, our result differs. In Holmstrom and Tirole (1997), bank capital is the minimum informed capital needed to incentivize bank monitoring – it is not optimally chosen by banks. We solve for the privately-optimal choice, setting the stage to examine effects of capital requirements. The private optimum $k(\lambda)$ strikes a balance between the benefit of capital in enabling a bank to *credibly* commit to screening (lowering the cost of uninsured deposits) and the equity cost.

[6]Rewrite L in (8) as $L = \frac{1}{1-\alpha\tilde{\gamma}(\lambda)}\left(\frac{\frac{(1-\lambda)^2}{2}k^2 + [r_E - 1 - (1-\lambda)^2]k + 1}{\lambda} + \alpha\delta\tilde{\gamma}(\lambda)k - \alpha\tilde{\gamma}(\lambda)\right)$. To show $\frac{\partial L}{\partial \lambda} < 0$, it suffices to show $\frac{[r_E - 1 - (1-\lambda)^2]k + 1}{\lambda}$ decreases with λ. Its derivative with respect to λ is $\frac{k(2-\lambda^2-r_E)-1}{\lambda^2}$. This is negative if $2 - \lambda^2 - r_E \leq 0$; if $2 - \lambda^2 - r_E > 0$, this derivative is less than $\frac{(2-\lambda^2-r_E)-1}{\lambda^2}$, again negative given $r_E > 1$. It is clear $\frac{\partial L}{\partial r_E} > 0$.

Since the marginal value of screening falls when the likelihood of encountering a bad project decreases (higher λ), $\frac{\partial k(\lambda)}{\partial \lambda} < 0$. Given this, if a minimum, risk-insensitive (λ-independent) capital requirement were imposed, it would bind for banks funding high-λ sectors, while banks funding low-λ sectors voluntarily raise more capital than the minimum requirement, given their stronger incentives to control deposit costs. The bank also keeps less capital when α and δ are higher, since these connote a more adverse impact of competition and greater bank capital erosion due to premature liquidation. It is intuitive that a higher capital cost r_E reduces $k(\lambda)$. The monotone relation between capital and screening ((2)) then implies banks screen less, hence $\gamma(\lambda)$ increases, as λ, α, δ and r_E increase.

A higher r_E reduces borrower surplus from bank finance, so more large firms switch to the market (λ_{mkt} decreases) and more bank-dependent small firms are cut off from banking (λ_{bank} increases).

Lastly, we characterize r_E by equating aggregate bank capital demand and supply:

$$2\int_{\lambda_{\text{bank}}}^{\lambda_{\text{mkt}}} k(\lambda) f(\lambda) d\lambda = K. \tag{16}$$

Due to the symmetry in the benchmark, brown and green banks have equal capital demand, $\int_{\lambda_{\text{bank}}}^{\lambda_{\text{mkt}}} k(\lambda) f(\lambda) d\lambda$, where $k(\lambda)$ is in (14), so the left-hand side (LHS) of (16) is the aggregate capital demand by all banks. The right-hand side (RHS), $K \in (0, 2)$, is the economy's total bank capital supply. When r_E rises, $k(\lambda)$ and λ_{mkt} decrease while λ_{bank} increases (Proposition 1), so the LHS strictly falls. So, r_E is unique if it exists. If $r_E = \infty$, there will be no demand for bank capital ($k(\lambda) = 0$), so the LHS falls to zero. The existence of $r_E > 1$ is guaranteed by letting K be small enough so the LHS exceeds K if $r_E = 1$. Once r_E is determined, other quantities in Proposition 1 are pinned down, as is the laissez-faire equilibrium.

4 Capital Requirement

4.1 Informal Discussion

Figure 1 illustrates the effects of a minimum capital requirement on brown loans. The black curve $k(\lambda)$ ((14)) plots the privately-optimal bank capital, brown (top) or green (bottom), in the laissez-faire. Recall in the laissez-faire, regardless of color, firms with $\lambda \geq \lambda_{\text{mkt}}$ obtain market finance, $\lambda \in (\lambda_{\text{bank}}, \lambda_{\text{mkt}})$

take bank loans, whereas those with $\lambda \leq \lambda_{\text{bank}}$ are rationed.

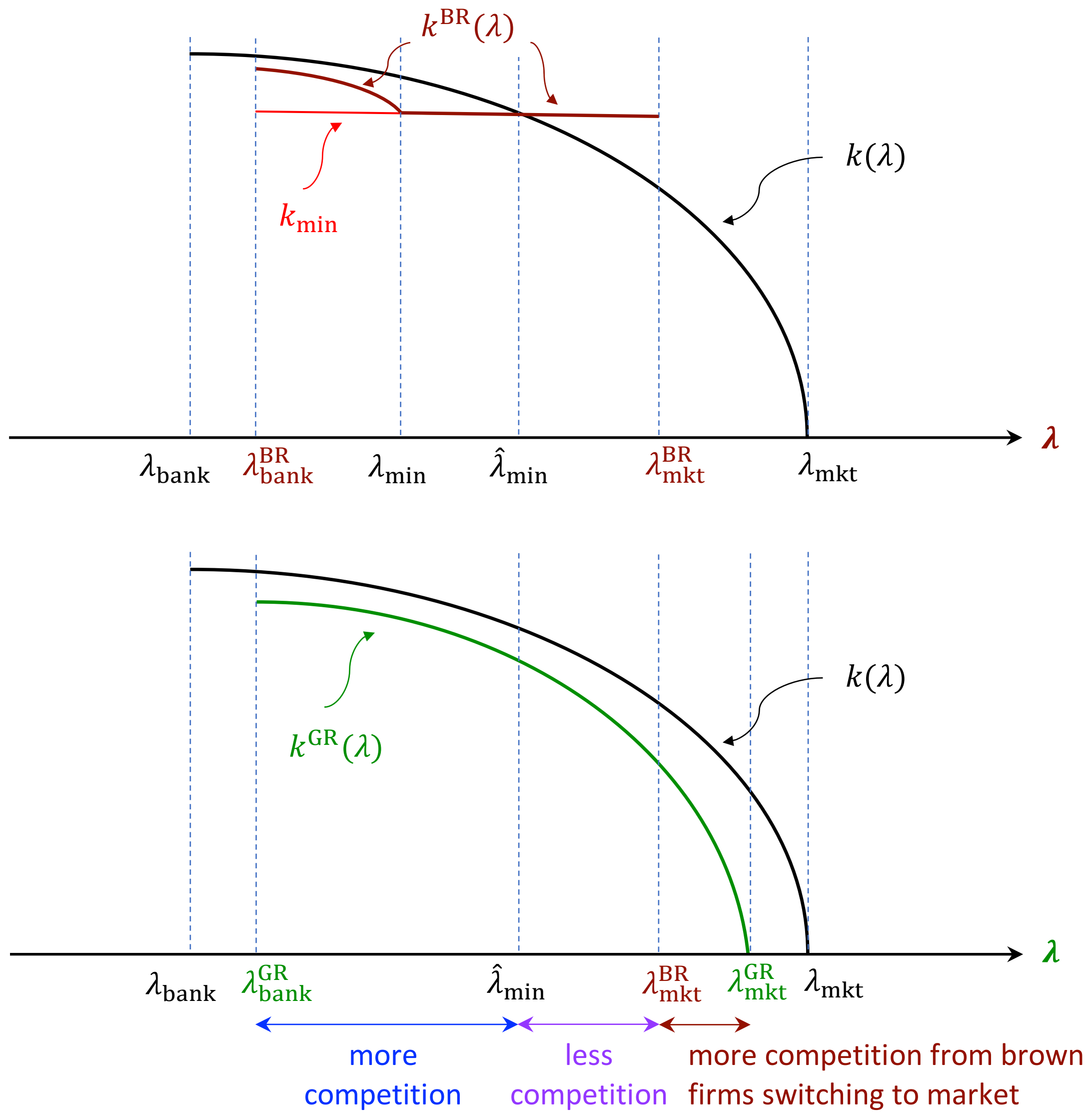

Figure 1: *Financial System under a Minimum Capital Requirement on Brown Loans*

Suppose a flat, risk-insensitive minimum capital requirement $k_{\min}$ (red line) is imposed on brown loans, with $k(\widehat{\lambda}_{\min}) = k_{\min}$. If cutoffs λ_{bank} and λ_{mkt} were unchanged both for brown and green firms, aggregate bank capital demand would increase, since banks funding brown firms $\lambda \in (\widehat{\lambda}_{\min}, \lambda_{\text{mkt}})$ raise $k_{\min}$, more than their laissez-faire private optimum $k(\lambda)$. Consequently, the capital cost must rise, say to r_E^{req}, to clear the market for bank capital. With a higher capital cost, λ_{bank} rises, while λ_{mkt} falls (Proposition 1). We use the superscript "BR" (*resp.* "GR") to denote equilibrium quantities for brown (*resp.* green) banks/firms with the minimum capital requirement.

Impact on Low-λ Firms: Suppose λ_{bank} rises for brown and green firms to $\lambda_{\text{bank}}^{\text{BR}}$ and $\lambda_{\text{bank}}^{\text{GR}}$, respectively. The elevated capital cost impacts brown and green banks equally in low-λ sectors, so $\lambda_{\text{bank}}^{\text{BR}} = \lambda_{\text{bank}}^{\text{GR}}$: imposing $k_{\min}$ on brown loans excludes an equal mass of low-λ brown and green firms from the financial system.

Impact on High-λ Firms: While a higher capital cost causes a bank-to-market switch for both high-λ brown and green firms (λ_{mkt} falls to $\lambda_{\text{mkt}}^{\text{BR}}$ and $\lambda_{\text{mkt}}^{\text{GR}}$ for brown and green firms, respectively), the impact is stronger for brown firms ($\lambda_{\text{mkt}}^{\text{BR}} < \lambda_{\text{mkt}}^{\text{GR}}$). Bank-funded high-$\lambda$ green firms suffer only the higher capital cost.[7] In contrast, bank-funded high-λ brown firms not only bear the elevated capital cost, but their banks also face binding capital requirements and hence raise more capital than is privately optimal. These two effects reinforce each other, so more brown firms exit banking than green firms.

A region $[\lambda_{\text{mkt}}^{\text{BR}}, \lambda_{\text{mkt}}^{\text{GR}}) \neq \varnothing$ exists. Green firms with $\lambda \in [\lambda_{\text{mkt}}^{\text{BR}}, \lambda_{\text{mkt}}^{\text{GR}})$ remain bank-funded, but now face more competition from brown firms in those sectors that switch to the market and always get funded. Thus, banks of these green firms reduce capital *beyond* the capital reduction driven by the elevated capital cost, *further* reducing screening, making more type-2 errors, and increasing bank risk.

Impact on Mid-λ Firms: For banks funding brown firms $\lambda \in (\lambda_{\text{bank}}^{\text{BR}}, \widehat{\lambda}_{\min}]$, their privately-optimal capital with the now higher cost $r_E^{\text{req}} > r_E$, denoted by $k^{\text{BR}}(\lambda)$, is lower than that in the laissez-faire, $k(\lambda)$ (obtained with r_E). So, there is a cutoff $\lambda_{\min} < \widehat{\lambda}_{\min}$, with $k^{\text{BR}}(\lambda_{\min}) = k_{\min} = k(\widehat{\lambda}_{\min})$. For relatively high-quality bank-funded brown firms, $\lambda \in (\lambda_{\min}, \lambda_{\text{mkt}}^{\text{BR}})$, the capital requirement binds – $k_{\min}$ exceeds the $k^{\text{BR}}(\lambda)$ they would raise with r_E^{req}. For relatively low-quality bank-funded brown firms, $\lambda \in (\lambda_{\text{bank}}^{\text{BR}}, \lambda_{\min})$, the capital requirement is not binding – their $k^{\text{BR}}(\lambda)$ with r_E^{req} already exceeds $k_{\min}$. The brown curve (top) plots brown banks' equilibrium capital with the capital requirement.

For green firms $\lambda \in (\lambda_{\text{bank}}^{\text{GR}}, \lambda_{\text{mkt}}^{\text{GR}})$, their banks are not directly subject to the capital requirement, but are indirectly affected by the elevated capital cost, which reduces each green bank's privately-optimal capital $k^{\text{GR}}(\lambda)$, indicated by the green curve (bottom),[8] relative to $k(\lambda)$ in the laissez-faire.

Summary: The capital requirement on brown loans increases all banks' capital cost in a general equilibrium, which pushes high-λ brown firms out of banking to the market and reduces capital raised by banks serving low-λ brown firms. These changes increase brown investments, intensifying within-

[7] The capital requirement targets brown banks exclusively.

[8] As explained, a subset of these green firms $\lambda \in [\lambda_{\text{mkt}}^{\text{BR}}, \lambda_{\text{mkt}}^{\text{GR}})$ also face greater competition from brown firms switching to the market, which further reduces $k^{\text{GR}}(\lambda)$ by banks financing those green firms.

sector competition for green firms. Green firms $\lambda \in [\lambda_{\text{mkt}}^{\text{BR}}, \lambda_{\text{mkt}}^{\text{GR}})$ face greater competition from brown firms switching to the market, and green firms $\lambda \in (\lambda_{\text{bank}}^{\text{GR}}, \widehat{\lambda}_{\min})$ face more competition from brown firms whose banks raise less capital than in the laissez-faire. This competition effect reinforces the elevated-capital-cost effect in *further* reducing the capital of banks funding these green firms, leading to more bad bank-funded green projects.

In the middle range, green firms $\lambda \in (\widehat{\lambda}_{\min}, \lambda_{\text{mkt}}^{\text{BR}})$ now face competing brown firms whose banks raise more capital than in the laissez-faire. This lowers competition from these brown firms, inducing banks of these green firms to also raise more capital. But the higher capital cost exerts a downward pressure on these green banks' capital demand. The net effect relative to the laissez-faire depends on the strength of the competition effect relative to the cost-of-capital effect.

4.2 Formal Analysis

We characterize variables in the above discussion, except (exogenous) $k_{\min}$, and hence the equilibrium with the capital requirement. We first take the higher capital cost r_E^{req} as given, and endogenize it later.

Lemma 2. *A bank serving a brown firm with $\lambda \in (\lambda_{\text{bank}}^{\text{BR}}, \lambda_{\min})$ raises capital*

$$k^{\text{BR}}(\lambda) = \frac{(1-\lambda)^2 - (r_E^{\text{req}} - 1 + \alpha\delta\lambda)}{(1-\lambda)^2(1-\alpha\delta\lambda)} \in \big(k_{\min}, k(\lambda)\big), \tag{17}$$

and lends with probability

$$\gamma^{\text{BR}}(\lambda) = \frac{r_E^{\text{req}} - (1-\lambda)^2}{1-\alpha\delta\lambda} > \gamma(\lambda). \tag{18}$$

A bank serving a green firm with $\lambda \in (\lambda_{\text{bank}}^{\text{GR}}, \lambda_{\min})$ raises capital $k^{\text{GR}}(\lambda) = k^{\text{BR}}(\lambda)$, and lends with probability $\gamma^{\text{GR}}(\lambda) = \gamma^{\text{BR}}(\lambda)$. The cutoffs, $\lambda_{\text{bank}}^{\text{BR}} = \lambda_{\text{bank}}^{\text{GR}} > \lambda_{\text{bank}}$, are determined by (13), replacing r_E there with r_E^{req}; $\lambda_{\min}$ is determined by $k^{\text{BR}}(\lambda_{\min}) = k_{\min}$:

$$\frac{(1-\lambda_{\min})^2 - (r_E^{\text{req}} - 1 + \alpha\delta\lambda_{\min})}{(1-\lambda_{\min})^2(1-\alpha\delta\lambda_{\min})} = k_{\min}. \tag{19}$$

Proof. Results follow Proposition 1 by replacing r_E with r_E^{req}. Since λ_{bank} increases with r_E (Proposition 1), $\lambda^{\text{BR}}_{\text{bank}} = \lambda^{\text{GR}}_{\text{bank}} > \lambda_{\text{bank}}$, given $r^{\text{req}}_E > r_E$. ■

While banks serving brown firms $\lambda \in (\lambda^{\text{BR}}_{\text{bank}}, \lambda_{\min})$ do not face binding capital requirements, $k^{\text{BR}}(\lambda) > k_{\min}$, they raise less capital than in the laissez-faire due to the elevated capital cost, $k^{\text{BR}}(\lambda) < k(\lambda)$. Consequently, they screen less, approve more brown loans, $\gamma^{\text{BR}}(\lambda) > \gamma(\lambda)$, and make more type-2 errors. The same is true for banks serving green firms $\lambda \in (\lambda^{\text{GR}}_{\text{bank}}, \lambda_{\min})$ due to the symmetry.

The analysis for banks serving brown firms $\lambda \in [\lambda_{\min}, \lambda^{\text{BR}}_{\text{mkt}})$ and banks serving green firms $\lambda \in [\lambda_{\min}, \lambda^{\text{GR}}_{\text{mkt}})$ is more involved, due to the asymmetry between brown and green banks in these sectors. While brown banks raise the required capital $k_{\min}$, green banks choose their privately-optimal capital, different from $k_{\min}$. The cutoffs $\lambda^{\text{BR}}_{\text{mkt}}$ and $\lambda^{\text{GR}}_{\text{mkt}}$ also differ.

Lemma 3 takes $\lambda^{\text{BR}}_{\text{mkt}}$ and $\lambda^{\text{GR}}_{\text{mkt}}$ as given, and examines brown and green banks in sectors $[\lambda_{\min}, \lambda^{\text{BR}}_{\text{mkt}})$.

Lemma 3. *A bank serving a brown firm with $\lambda \in [\lambda_{\min}, \lambda^{\text{BR}}_{\text{mkt}})$ raises capital*

$$k^{\text{BR}}(\lambda) = k_{\min}, \tag{20}$$

and lends with probability

$$\gamma^{\text{BR}}(\lambda) = 1 - (1-\lambda)^2 k_{\min}. \tag{21}$$

A bank serving a green firm with $\lambda \in [\lambda_{\min}, \lambda^{\text{BR}}_{\text{mkt}})$ raises capital

$$k^{\text{GR}}(\lambda) = 1 - \frac{r^{\text{req}}_E - 1 + \lambda\alpha\delta\gamma^{\text{BR}}(\lambda)}{(1-\lambda)^2} = 1 - \frac{r^{\text{req}}_E - 1 + \lambda\alpha\delta}{(1-\lambda)^2} + \lambda\alpha\delta k_{\min}, \tag{22}$$

and lends with probability

$$\gamma^{\text{GR}}(\lambda) = r^{\text{req}}_E - (1-\lambda)^2 + \lambda\alpha\delta\gamma^{\text{BR}}(\lambda) = r^{\text{req}}_E - (1-\lambda)^2(1 + \lambda\alpha\delta k_{\min}) + \lambda\alpha\delta. \tag{23}$$

Proof. $k^{\text{BR}}(\lambda) = k_{\min}\ \forall \lambda \in [\lambda_{\min}, \lambda^{\text{BR}}_{\text{mkt}})$, since the capital requirement binds for brown banks serving sectors $\lambda \in [\lambda_{\min}, \lambda^{\text{BR}}_{\text{mkt}})$. Using $\theta = (1-\lambda)k^{\text{BR}}(\lambda)$ ((2)), $\gamma^{\text{BR}}(\lambda) = \lambda + (1-\lambda)(1-\theta) = 1 - (1-\lambda)^2 k_{\min}$. Replacing r_E with r^{req}_E and $\tilde{\gamma}(\lambda)$ with $\gamma^{\text{BR}}(\lambda)$ in (9) yields (22). Lastly, $\gamma^{\text{GR}}(\lambda) = \lambda + (1-\lambda)(1-\theta) = 1 - (1-\lambda)^2 k^{\text{GR}}(\lambda)$, yielding (23). ■

Next, we examine bank-funded green firms in sectors $[\lambda_{\text{mkt}}^{\text{BR}}, \lambda_{\text{mkt}}^{\text{GR}})$ which, as discussed in Section 4.1, face greater competition from brown firms switching from banks to the market.

Lemma 4. *A bank serving a green firm with $\lambda \in [\lambda_{\text{mkt}}^{\text{BR}}, \lambda_{\text{mkt}}^{\text{GR}})$ raises capital*

$$k^{\text{GR}}(\lambda) = 1 - \frac{r_E^{\text{req}} - 1 + \lambda\alpha\delta}{(1-\lambda)^2} < k(\lambda), \tag{24}$$

and lends with probability

$$\gamma^{\text{GR}}(\lambda) = r_E^{\text{req}} - (1-\lambda)^2 + \lambda\alpha\delta > \gamma(\lambda). \tag{25}$$

Proof. Because competing brown firms in sectors $\lambda \in [\lambda_{\text{mkt}}^{\text{BR}}, \lambda_{\text{mkt}}^{\text{GR}})$ switch to the market, we let $\gamma^{\text{BR}}(\lambda) = 1$ in (22) and (23), yielding (24) and (25), respectively. ■

The lack of market screening increases the odds of funding for brown firms switching from banks to the market. The resulting elevated competition for green firms in sectors $\lambda \in [\lambda_{\text{mkt}}^{\text{BR}}, \lambda_{\text{mkt}}^{\text{GR}})$ causes their banks to raise less capital, screen less, approve more green loans, and make more type-2 errors. This *competition effect* reinforces the cost-of-capital effect ($r_E^{\text{req}} > r_E$) in reducing capital and screening by green banks serving sectors $\lambda \in [\lambda_{\text{mkt}}^{\text{BR}}, \lambda_{\text{mkt}}^{\text{GR}})$.

We now characterize $\lambda_{\text{mkt}}^{\text{BR}}$ and $\lambda_{\text{mkt}}^{\text{GR}}$. First, $\lambda_{\text{mkt}}^{\text{GR}}$ is the value of λ when $k^{\text{GR}}(\lambda) = 0$ in (24). When the green bank finds it optimal to raise zero capital, it is equivalent to market finance.

$$1 - \frac{r_E^{\text{req}} - 1 + \lambda_{\text{mkt}}^{\text{GR}}\alpha\delta}{(1-\lambda_{\text{mkt}}^{\text{GR}})^2} = 0 \quad \Rightarrow \quad \lambda_{\text{mkt}}^{\text{GR}} = \frac{(2+\alpha\delta) - \sqrt{(2+\alpha\delta)^2 - (8 - 4r_E^{\text{req}})}}{2}. \tag{26}$$

Note $\lambda_{\text{mkt}}^{\text{GR}} < \lambda_{\text{mkt}}$ (given by (12)), given $r_E^{\text{req}} > r_E$. For a sector-λ brown firm, its expected profit from market finance is $\pi_{\text{mkt}} = \lambda(1-\alpha)X - (1-\lambda\alpha)$; see (11). Its expected profit from bank finance is $\pi_{\text{bank}} = \lambda[1-\alpha\gamma^{\text{GR}}(\lambda)]X - \left[\frac{(1-\lambda)^2}{2}k_{\min}^2 + [r_E^{\text{req}} - 1 + \lambda\alpha\delta\gamma^{\text{GR}}(\lambda) - (1-\lambda)^2]k_{\min} + 1 - \lambda\alpha\gamma^{\text{GR}}(\lambda)\right]$,[9] where $\gamma^{\text{GR}}(\lambda)$ is in (25). The cutoff $\lambda_{\text{mkt}}^{\text{BR}}$ is the value of λ when $\pi_{\text{mkt}} = \pi_{\text{bank}}$.[10] We have verified $\lambda_{\text{mkt}}^{\text{BR}} < \lambda_{\text{mkt}}^{\text{GR}}$.[11]

[9] This follows (4) and (8), replacing $\tilde{\gamma}(\lambda)$ with $\gamma^{\text{GR}}(\lambda)$.

[10] It can be shown $\pi_{\text{mkt}} > \pi_{\text{bank}}$ for $\lambda > \lambda_{\text{mkt}}^{\text{BR}}$, while $\pi_{\text{mkt}} < \pi_{\text{bank}}$ for $\lambda < \lambda_{\text{mkt}}^{\text{BR}}$.

[11] Consider a sector-$\lambda_{\text{mkt}}^{\text{GR}}$ brown firm. If it were bank funded, the (brown) bank would face the binding capital requirement $k_{\min}$. Since a sector-$\lambda_{\text{mkt}}^{\text{GR}}$ green firm is funded by a green bank that raises its privately-optimal capital (instead of $k_{\min}$), the green firm makes a higher profit than the brown firm. Therefore, given $\pi_{\text{bank}} = \pi_{\text{mkt}}$ at $\lambda = \lambda_{\text{mkt}}^{\text{GR}}$ for a green firm, we must have $\pi_{\text{bank}} < \pi_{\text{mkt}}$ at $\lambda = \lambda_{\text{mkt}}^{\text{GR}}$ for a brown firm (note π_{mkt} is the same for both brown and green firms at

Finally, we determine r_E^{req}:

$$\underbrace{\int_{\lambda_{\text{bank}}^{\text{BR}}}^{\lambda_{\min}} k^{\text{BR}}(\lambda)f(\lambda)d\lambda + \int_{\lambda_{\min}}^{\lambda_{\text{mkt}}^{\text{BR}}} k_{\min}f(\lambda)d\lambda}_{\text{aggregate capital demand by brown banks}}$$
$$+\underbrace{\int_{\lambda_{\text{bank}}^{\text{GR}}}^{\lambda_{\min}} k^{\text{GR}}(\lambda)f(\lambda)d\lambda + \int_{\lambda_{\min}}^{\lambda_{\text{mkt}}^{\text{BR}}} k^{\text{GR}}(\lambda)f(\lambda)d\lambda + \int_{\lambda_{\text{mkt}}^{\text{BR}}}^{\lambda_{\text{mkt}}^{\text{GR}}} k^{\text{GR}}(\lambda)f(\lambda)d\lambda}_{\text{aggregate capital demand by green banks}} = K, \tag{27}$$

where $k^{\text{BR}}(\lambda)$ is in (17), $k^{\text{GR}}(\lambda)$ is also given by (17) for $\lambda \in (\lambda_{\text{bank}}^{\text{GR}}, \lambda_{\min})$, by (22) for $\lambda \in [\lambda_{\min}, \lambda_{\text{mkt}}^{\text{BR}})$, and by (24) for $\lambda \in [\lambda_{\text{mkt}}^{\text{BR}}, \lambda_{\text{mkt}}^{\text{GR}})$. Existence and uniqueness of r_E^{req} can be shown as for r_E.

4.3 Pollution and Stability

Relative to the laissez-faire, brown banks serving sectors $(\lambda_{\text{bank}}^{\text{BR}}, \widehat{\lambda}_{\min})$ raise less capital, while those serving sectors $(\widehat{\lambda}_{\min}, \lambda_{\text{mkt}}^{\text{BR}})$ raise more capital with the capital requirement. As explained in Section 4.1, $\widehat{\lambda}_{\min}$ is determined by $k(\widehat{\lambda}_{\min}) = k_{\min}$:

$$\frac{(1-\widehat{\lambda}_{\min})^2 - (r_E - 1 + \alpha\delta\widehat{\lambda}_{\min})}{(1-\widehat{\lambda}_{\min})^2(1-\alpha\delta\widehat{\lambda}_{\min})} = k_{\min}. \tag{28}$$

Relative to the laissez-faire, the economy-wide change in pollution is

$$\Delta\text{Po} = \omega \left[\begin{array}{l} -\underbrace{\int_{\lambda_{\text{bank}}}^{\lambda_{\text{bank}}^{\text{BR}}} \gamma(\lambda)f(\lambda)d\lambda}_{\text{denied bank credit}} - \underbrace{\int_{\widehat{\lambda}_{\min}}^{\lambda_{\text{mkt}}^{\text{BR}}} [\gamma(\lambda) - 1 + (1-\lambda)^2 k_{\min}]f(\lambda)d\lambda}_{\text{raise more capital}} \\ +\underbrace{\int_{\lambda_{\text{bank}}^{\text{BR}}}^{\lambda_{\min}} \frac{r_E^{\text{req}} - r_E}{1-\lambda\alpha\delta} f(\lambda)d\lambda + \int_{\lambda_{\min}}^{\widehat{\lambda}_{\min}} [1-(1-\lambda)^2 k_{\min} - \gamma(\lambda)]f(\lambda)d\lambda}_{\text{raise less capital}} \\ +\underbrace{\int_{\lambda_{\text{mkt}}^{\text{BR}}}^{\lambda_{\text{mkt}}} [1-\gamma(\lambda)]f(\lambda)d\lambda}_{\text{exit to market}} \end{array} \right], \tag{29}$$

where $\gamma(\lambda) = \frac{r_E - (1-\lambda)^2}{1-\lambda\alpha\delta}$ ((15)). Terms in the bracket of (29) compute the capital-requirement-induced net change in the mass of funded brown projects (each producing pollution ω). The first two terms

$\lambda = \lambda_{\text{mkt}}^{\text{GR}}$). Thus, $\lambda_{\text{mkt}}^{\text{BR}} < \lambda_{\text{mkt}}^{\text{GR}}$.

measure brown reduction: (i) brown firms in sectors $\lambda \in (\lambda_{\text{bank}}, \lambda^{\text{BR}}_{\text{bank}}]$ receive bank funding with probability $\gamma(\lambda)$ in the laissez-faire but are now denied credit; and (ii) brown banks serving sectors $\lambda \in (\widehat{\lambda}_{\min}, \lambda^{\text{BR}}_{\text{mkt}})$ raise more capital, screen more, reducing the odds of brown funding by $\gamma(\lambda) - \gamma^{\text{BR}}(\lambda)$, where $\gamma^{\text{BR}}(\lambda) = 1 - (1-\lambda)^2 k_{\min}$ ((21)). However, our preceding analysis reveals the capital requirement also increases brown investments in other sectors, as reflected in the next three terms: (iii) brown banks serving sectors $\lambda \in (\lambda^{\text{BR}}_{\text{bank}}, \lambda_{\min})$ raise less capital and increase the odds of brown funding by $\gamma^{\text{BR}}(\lambda) - \gamma(\lambda) = \frac{r_E^{\text{req}} - r_E}{1-\lambda\alpha\delta}$, where $\gamma^{\text{BR}}(\lambda) = \frac{r_E^{\text{req}} - (1-\lambda)^2}{1-\alpha\delta\lambda}$ ((18)); (iv) changes are similar for brown investments in sectors $\lambda \in (\lambda_{\min}, \widehat{\lambda}_{\min})$, except $\gamma^{\text{BR}}(\lambda) = 1 - (1-\lambda)^2 k_{\min}$ ((21)); and (v) bank-to-market switch by brown firms in sectors $\lambda \in [\lambda^{\text{BR}}_{\text{mkt}}, \lambda_{\text{mkt}})$ increases the odds of brown investment by $1 - \gamma(\lambda)$.

The implicit determination of several variables in (29) prevents an analytical determination of ΔPo's sign. Intuitively, if the λ-distribution places a large mass around high-λ sectors, then the effect of high-λ brown firms' bank-to-market switch dominates, leading to a positive ΔPo (more pollution). ΔPo will also be positive if the distribution assigns a large mass around mid/low-λ sectors because brown banks serving those sectors reduce capital. Conversely, ΔPo will be negative (less pollution) if the distribution has a large mass around low-λ sectors (so the effect of low-λ brown firms' exclusion from the financial system prevails), and/or mid/high-λ sectors (so the effect of capital increase by brown banks serving those sectors dominates). These are confirmed by our (unreported) numerical analysis.

We now examine bank stability, defined as (inverse of) the mass of failed bank-funded projects. Stability is not synonymous with social welfare. For instance, while denying bank credit to low-λ firms or pushing high-λ firms to market finance reduces project failure *within* banking and increases bank stability, it also reduces economy-wide investments and hence may lower social surplus.

Proposition 2 (Pollution and Stability)**.** *The capital requirement's impact on economy-wide pollution is ambiguous. The requirement lowers stability of green banks serving sectors* $\lambda \in [\lambda^{\text{BR}}_{\text{mkt}}, \lambda^{\text{GR}}_{\text{mkt}}) \cup (\lambda^{\text{GR}}_{\text{bank}}, \widehat{\lambda}_{\min}]$ *and brown banks serving sectors* $\lambda \in (\lambda^{\text{BR}}_{\text{bank}}, \widehat{\lambda}_{\min})$*, while increases stability of brown banks serving sectors* $\lambda \in (\widehat{\lambda}_{\min}, \lambda^{\text{BR}}_{\text{mkt}})$*. This stability effect is ambiguous for green banks serving sectors* $\lambda \in (\widehat{\lambda}_{\min}, \lambda^{\text{BR}}_{\text{mkt}})$*.*

Proof. Results on pollution are shown earlier. Since stability hinges on screening and hence bank capital, results on brown bank stability follow the explanation of (29) for brown banks' capital change. For green banks serving sectors $\lambda \in [\lambda^{\text{BR}}_{\text{mkt}}, \lambda^{\text{GR}}_{\text{mkt}})$ or $\lambda \in (\lambda^{\text{GR}}_{\text{bank}}, \widehat{\lambda}_{\min}]$, their capital and hence stability fall because of the elevated competition from same-sector brown firms switching to the market (the former) or same-sector brown banks raising less capital (the latter). For green bank serving sectors $\lambda \in (\widehat{\lambda}_{\text{min}}, \lambda^{\text{BR}}_{\text{mkt}})$, while the increased capital cost reduces their capital demand, higher capital raised by same-sector brown banks induces them to also raise more capital; the net effect is ambiguous. ■

5 Implications

Capital Requirement: How should a regulator choose k_{min}? While imposing k_{min} excludes some low-λ brown firms from the financial system, it also squeezes out low-λ green firms due to the general equilibrium effect of a higher bank capital cost. The effect on high-λ sectors is more surprising and complex. Because more high-λ brown firms go to the market, the competitive pressure on bank-funded green firms increases – the lack of market screening means the market funds more brown firms than banks would. This effect, which distinguishes our paper sharply from earlier work, is a double whammy for a regulator concerned about both banking risk and pollution – now there is *greater* pollution from high-λ brown firms, and *less* capital in banks funding competing green firms. This latter effect gets stronger with greater brown-green competition. The socially-optimal k_{min} will reflect these tradeoffs.

Other Possible Policy Responses: Regulators may mute the general equilibrium cost-of-capital effect by infusing capital into banking. This can be done via equity purchases as in the Capital Purchase Program (CPP) during the 2007-09 financial crisis. The capital provision could even be subsidized, which would require a reallocation of government funding, so the general equilibrium effects would need to be carefully examined.

This approach will not mute the competition channel, which operates as long as brown firms can access market finance. Bank regulators need to deeply understand the nature of brown-green competition in any bank-funded sector, and modify accordingly stress tests involving various capital requirement scenarios. This seems a complicated exercise and takes regulators into an analysis of the industrial organization of the economy and the effects of competitive dynamics. Moreover, if we interpret high-λ firms as large firms generating more pollution, then the pollution effect from their bank-to-market migration can be significant. Generally speaking, our analysis should cause regulators to pause in contemplating higher capital requirements on brown loans, given their unintended consequences.

6 Conclusion

We have examined the effects of using bank capital requirements to reduce brown lending. Such initiative will affect the bank capital cost via general equilibrium effects, cause green banks to lower their capital in their loans to the largest and smallest green firms, and potentially *increase* pollution as large brown firms switch from banks to the market. An important takeaway for proponents of the idea that the banking system may be used to achieve climate objectives is that even firms borrowing from banks have alternative financing sources, so inducing these firms to exit banking may lead to outcomes that are the opposite of those desired.

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