ESG risk, investment timing and corporate debt structure

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Abstract

This study examines the impact of Environmental, Social, and Governance (ESG) risks on firms' investment decisions, leverage and debt structure. Using a contingent claim model that incorporates both existing assets and growth options, we analyze how firms balance bank and public debt financing under varying levels of ESG risk. Our findings show that higher ESG risk leads to delays in exercising growth options, increased leverage at the time of investment, and a shift from bank debt to public debt and elevated renegotiation and default thresholds. These outcomes align with empirical evidence. Additionally, we explore how firms time their investments in ESG risk reduction. We find that such investments occur earlier in environments with lower renegotiation failure risk, lower bankruptcy costs, higher tax rates, lower risk-free rates and under market conditions of lower volatility and higher growth in demand or higher anticipated value of growth options. Furthermore, we investigate the role of debt financing constraints on ESG investment timing and firm debt structure. Our results reveal a U-shaped relationship between debt constraints and ESG investment timing—firms accelerate ESG investments under mild constraints but delay them when constraints become more binding. This pattern also influences the composition of debt financing, with moderate constraints increasing reliance on bank debt and stricter constraints reducing it in favor of public debt.

Keywords: real options, corporate social responsibility, environmental social governance, investment timing, capital structure, debt structure debt renegotiation.

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1. Introduction

Firms face increasing concerns regarding the impact of Environmental, Social, and Governance (ESG) risks on their investments and access to debt financing. ESG risks may cause significant harm to a firm's value chain, arising, for example, from climate-related disasters, labor-related issues such as workplace accidents and reduced safety standards, or poor governance practices that increase corruption. Firms also face transition risks as regulators become increasingly stringent in enforcing stricter rules, which, if not satisfied, can result in substantial penalties or even force a firm out of the market. Importantly, on the financing side, equity investors, banks, and public bondholders have become more sensitive in their investment choices, particularly regarding the pricing and cost of capital impacts of ESG risks (Feldhütter and Pedersen, 2024).

In such an uncertain environment caused by elevated ESG risks, it is important to understand how firms navigate by formulating their investments in new growth opportunities and making financing and debt structure decisions. However, despite the relevance of this issue and the exponential interest of academics in ESG related issues (see Gillan et al., 2021, for a review), surprisingly, the relationship between ESG risks and firms' investment, capital structure and debt structure decisions has received very little attention in the literature, both empirically and theoretically.

On the empirical side, very recent, yet scarce preliminary empirical evidence exists on the relationship between ESG risk and capital structure or debt structure. Ginglinger and Moreau (2023) show that exposure to physical climate risk decreases firm leverage in the post-2015 period. This is driven by both a demand effect (firms' optimal leverage decreases) and a supply effect (lenders require a higher compensation, increasing spreads when lending to firms with higher risk). Asimakopoulous et al. (2023) find that firms that become ESG-rated reduce their target leverage ratios to avoid debt overhang and underinvestment issues. Moreover, they show that ESG-rated firms increase the use of bank financing and reduce the use of bond financing. Similarly, Newton et al. (2024) show that firms with higher ESG reputation risk rely more on public debt than on bank loans.

In the theoretical literature, Nishihara (2024) models a firm's choice between a sustainable project with a high investment cost and an unsustainable project with ESG risk but low investment cost. He shows that the firm invests later in the sustainable project (due to higher investment cost), but that the unsustainable project uses higher leverage. Diakho and Moraux

(2024) propose a model in which global warming impacts the stranding of assets upon liquidation, thus affecting a firm's optimal capital structure. They find that the higher the exposure to global warming, the lower the leverage.

However, to the best of our knowledge, the relationship between ESG risks and debt structure has not been analyzed before. To fill this gap, in this paper, we develop a contingent claim model where a firm with assets in place also holds a growth option to expand operations. The firm is initially financed with common equity and has the possibility to exercise its growth option at any time. To finance the cost of investment, the firm can issue a mixture of equity and debt where debt can arise either from bank financing or a public bond issue. To capture the differences between these two forms of debt, we assume that bank financing can be renegotiated, unlike public debt. Following Hackbarth et al. (2007), this is the only distinction between the two debt types in our model. We model ESG risk as having an exponentially distributed frequency of a jump-to-ruin event in assets, effectively reducing the anticipated useful lifespan of the firm's assets.

First, we seek to understand how higher levels of ESG risks affect a firm's exercise of growth options, the timing of its renegotiation with bank lenders, and its overall default timing, as well as the impact on the firm's leverage ratio and debt structure between bank and public debt. We find that higher ESG risk levels result in lower firm value, delays in the firm's exercise of growth opportunities, higher leverage when the firm exercises its investment options, and a lower proportion of bank debt relative to public debt. Higher ESG risk increases credit risk by raising the likelihood of renegotiation and default triggers.

The mechanism through which higher ESG risk increases leverage ratios while reducing the use of bank debt is driven by a reduction in the expected present value of cash flows due to a higher effective discount rate, which leads to delays in investment. These delays allow firms to issue higher coupon rates on both public and bank debt since cash flows are higher at the time of investment. However, ESG risk raises the discount rate on future cash flows, reducing the present value of bank debt coupons and recovery values in bankruptcy, causing bank debt to decrease with higher ESG risk. On the contrary, public debt increases with ESG risk as the positive effect of higher coupon rates outweighs the negative impact of the discount rate. Consequently, this lowers the proportion of bank debt in the firm's overall debt structure in response to higher ESG risk. Since bank debt allows firms to minimize bankruptcy costs, they will leverage bank debt as much as possible before turning to market debt. Hence, the total debt value decreases with ESG risk, although at a lower pace compared to firm value, thus resulting in higher leverage ratios.

Our predictions regarding leverage and debt structure closely align with recent empirical evidence. Newton et al. (2024) show that firms with higher ESG reputation risks prefer public bonds over bank loans, while Asimakopoulos et al. (2023) find that firms with lower ESG risk exposure reduce their target leverage ratios, increase the use of bank financing, and decrease reliance on bond financing.

Secondly, we explore a firm's proactive investment in reducing ESG risk. We find that investments in ESG risk reduction are initiated earlier in environments characterized by a lower probability of renegotiation failure, lower bankruptcy costs, higher tax rates, and a lower risk-free rate. Conversely, greater renegotiation power of debt holders does not influence the timing of ESG investments.

Several of these factors (such as tax rates) can be influenced by regulators, suggesting that our framework offers insights for promoting ESG investments. Other factors can be further encouraged by governments; for example, implementing regulatory frameworks that reduce renegotiation failures or lower liquidation costs (e.g., minimizing delays in the litigation process) may help accelerate ESG investment. Additionally, we find that market-related conditions—such as lower volatility, a higher value of growth options (due to greater expansion potential or lower investment costs), and a higher revenue growth rate—also contribute to the faster adoption of ESG initiatives.

We provide rich empirical implications with respect to the capital and debt structure of firms engaging in growth investments with a focus on reducing the impact of ESG risk. We show that firms investing in ESG are expected to have lower leverage ratios and a higher proportion of bank financing when facing higher volatility, higher probability of renegotiation failure, lower growth rate of revenues, higher investment cost, lower tax rate, and a lower risk-free rate. Higher renegotiation power of debt holders does not affect leverage ratios but increases the proportion of bank financing. A higher growth expansion factor of growth options does not affect leverage ratios and the proportion of debt financing.

Thirdly, given the substantial evidence in the literature highlighting firms' exposure to debt financing constraints[1], we examine how these constraints impact firms' decisions to undertake ESG investments aimed at reducing ESG risk. We find that the timing of ESG investments follows a U-shaped pattern in relation to debt financing constraints: under small to moderate constraints (relative to unconstrained debt levels), firms accelerate ESG investments. However, as constraints become more binding, firms delay ESG investments.

Additionally, we find that less severe debt financing constraints accelerate renegotiation and bankruptcy timing due to increased debt usage. Our analysis provides important predictions about a firm's debt structure, showing that the proportion of bank debt financing follows an inverse U-shaped relationship with debt financing constraints. This suggests that mild constraints lead to greater reliance on bank debt financing, but as constraints become more severe, the proportion of bank financing in the firm's debt structure declines.

Of particular importance are constraints that limit the amount of debt issuance to an amount just sufficient to cover investment costs. In this range of debt financing constraints, we anticipate that firms will significantly delay ESG risk reduction investments compared to unconstrained levels and rely much more heavily on bank debt in their capital structure.

We proceed as follows. Section 2 provides a literature review and discusses our contributions. Section 3 provides the model setup, while section 4 provides the model solution. Section 5 derives model propositions and predictions based on extensive numerical simulations, while section 5 concludes.

2. Related literature and contributions

2.1. ESG risk, investment and financing

A recent emerging strand of the asset pricing literature seeks to incorporate climate risk into corporate bond pricing. For example, Agliardi and Agliardi (2019) propose a structural model to value green bonds and measure the so-called "greenium", the difference between the yields on a conventional bond and a green bond with the same characteristics, in which brown firms face an ad hoc penalty. In Agliardi and Agliardi (2021) two sources of uncertainty are

[1] Empirical research by Rauh (2006) and Hubbard, Kashyap, and Whited (1995) shows that firms face financing constraints in debt and equity markets. Whited and Wu (2006) and Gomes, Yaron, and Zhang (2006) show that financing constraints is a significant risk factor for firm returns. Firms encounter debt financing constraints due to various frictions including moral hazard or asymmetric information issues.

introduced, related to firm cash flows and the effectiveness of the financed green project to better understand the determinants of green bond prices and the greenium. However, these papers focus on corporate bond pricing, and do not analyse optimal capital structure.

First attempts to relate ESG risk with capital structure have been done by Nishihara (2023) and Diakho and Moraux (2024). Nishihara (2023) analyses a firm's choice between sustainable and unsustainable projects, trading off a higher ESG risk against lower investment costs. He focuses on how firms optimize their project choice, investment timing, and capital structure to maximize financial value. Similarly to us, he finds that firms investing in unsustainable projects tend to use higher leverage. Diakho and Moraux (2024) propose a structural model in which global warming affects the stranding of assets in liquidation, thus impacting capital structure. They show that the higher the firm's exposure to global warming, the lower its leverage. Nevertheless, both works consider a single type of debt in their framework. In contrast, our model accounts for debt heterogeneity, thus providing implications for firms' optimal debt structure. Moreover, we also consider the impact of debt financing constraints.

2.2. Investment timing and debt structure

Our work builds on contingent claims models examining investment timing and debt structure. Hackbarth et al. (2007) develop a model to investigate the conditions under which firms select specific debt structures, accounting for the ability of banks to renegotiate debt in private workouts. They find that bank debt offers a superior trade-off between tax shields and bankruptcy costs due to its flexibility in renegotiation. However, bank debt capacity is limited, and firms leverage it to a certain extent before turning to market debt. They show that small/weak firms exclusively use bank debt due to their limited bargaining power and higher bankruptcy risks. Large/strong firms, on the other hand, utilize a mix of bank and market debt, placing bank debt in a senior position to maximize efficiency. Senior bank debt minimizes bankruptcy costs by leveraging the bank's ability to renegotiate. Market debt, while offering additional tax shields, increases the risk of inefficient liquidation due to its inflexible nature. We incorporate ESG risk into their framework and analyse the impact of ESG risk on firms' optimal capital structure and debt structure.

Morellec et al. (2015) investigate the dynamics of firms' decisions between using public bonds or private bank loans to finance investments. In their model, firms face potential scarcity in bank financing at times of investment due to search costs associated with finding informed lenders when seeking to raise private debt. As a result, firms may seek to supplement equity financing with debt financing from public bonds to avoid financing shortages. Our model shares several common characteristics, such as modelling a firm with existing assets and growth options. However, while in their model firms have to choose between either using bank debt or public debt, in our model firms can use a mixture of bank debt and bonds. More importantly, our focus is on ESG risk. Unlike their model, where firms risk losing the investment opportunity to competitors before investing, in our case, firms face ESG risk that persists even after the exercise of growth or ESG investments. Moreover, we do not impose any restrictions on the availability of bank financing sources. Thus, the balance between bank and public debt is driven by the relative advantage of bank debt and the capacity limits of utilizing this source before resorting to public debt. In the debt-constrained version of our model, debt constraints apply to both sources of debt, not only bank debt.[2]

Gan et al. (2022) examine the interplay between heterogeneous debt structures and corporate investment and financing decisions in the context of a dynamic trade-off model. Our model shares several common modelling characteristics with respect to the modelling of debt structure and, in particular, the renegotiation process of bank debt. However, we model growth options involving lump-sum investment costs enhancing project revenues (see also Morellec et al., 2015), while they focus on the dynamic investment setting of Diamond and He (2014). Their setting thus provides insights into how a mix of bank and market debt affects investment and debt overhang. In contrast, our model focuses on the modelling of ESG risk and its impact on debt structure, as well as the investment timing to reduce this risk. We also explore issues related to the impact of debt financing constraints for firms contemplating growth investments with ESG components.

3. Base case model setup

3.1. Cash flows, growth options and ESG risk

We consider a fully equity financed firm with assets in place which generate an EBIT with initial value X_0 that evolves according to the following process:

$$dX(t) = \mu X(t)dt + \sigma X(t) \tag{1}$$

where μ is a parameter reflecting the trend, σ is the volatility, and $dz(t)$ is the increment of a Wiener process. Corporate income is taxed at a rate τ and let r denote the risk-free interest rate.

[2] Our model can easily accommodate scenarios where a firm faces constraints on only one source of financing. Specifically, a situation in which the firm encounters supply restrictions on bank financing represents a special case of our model, where constraints are applied solely to bank borrowing.

Due to ESG risks, *X(t)* matures at a random time, which follows an exponential distribution with rate λ (≥ 0). The maturity represents the time of the firm's exit from the market.

The firm has the option to invest in a growth option with investment cost *I* which can take place at an optimal time X_I. The growth option expands the value of assets in place revenues by *ex*. We consider also the case where the investment cost can be used for ESG investments aiming to reduce the impact of ESG risk by k. Assume that investment can be broken down in two parts with a fraction of investment allocated to ESG friendly assets. The reduction in ESG risk depends on how much of the investment is allocated to ESG friendly assets. Namely, a higher percentage of ESG investment results in a larger reduction in ESG risk, k. In a perfect information setting, investors are aware of the exact proportion allocated to ESG and hence have full information regarding the expected reduction of ESG risk.

3.2. Debt structure and default following investment

We assume that the firm issues two classes of perpetual debt at investment: bank debt and market debt. Their respective promised flow coupons are b and c. The bank debt value function is denoted B, and the market debt value function is denoted C. For firm's equity value we use the notation E.

Following Hackbarth et al. (2007) and Gan et al. (2022), we assume that due to the dispersion of debt holders, payments to market lenders cannot be changed outside of the formal bankruptcy process, in line with empirical evidence from Gilson et al. (1990) and Asquith et al. (1994).

In contrast, bank debt can be renegotiated within a costly private workout. This is the only difference between market and bank debt in our model. Renegotiation timing is optimally decided by equityholders to maximize equity value, and is defined as the first time the cash flow v_t reaches from above the endogeneous renegotiation threshold v_n. As in Gan et al. (2022), through debt restructuring the firm undertakes a permanent coupon reduction, with the coupon payment being reduced from b to b_n with $b_n < b$ due the coupon haircut. However, unlike Gan et al. (2022), in our model b_n is not exogenous. Following Hackbart et al. (2007), we assume that the equityholders make a take it or leave it offer to the bank. The reduced coupon b_n is endogenously determined and the outcome of the non-cooperative bargaining game depends on the relative bargaining power of the two parties and on their outside options, i.e., the payoffs that the parties obtain in case renegotiation fails and the firm is liquidated (Moraux and Silaghi, 2014). Specifically, in the case of "strong" equity holders that have the full negotiating power, the bank lenders are pushed to accept a renegotiation that sets the value of their claim equal to their reservation value at renegotiation (i.e., bank bargaining power is given by $\eta = 1$). When bank lenders have some bargaining power as well ($\eta > 1$), they obtain a value larger than their reservation value.

Following previous literature, we assume that in case of liquidation the absolute priority rule (APR) strictly applies, so that the outside option for equityholders is zero. Moreover, a fraction of the asset value, $\alpha \in (0,1)$ is lost, in the form of bankruptcy costs. This implies that both market debt holders and bank debt lenders jointly share liquidation value $L(v_t)$, given by:

$$L(v_t) = (1 - \alpha)U(v_t) \qquad (2)$$

where $U(v_t)$ represents the after-tax value of an all-equity financed (unlevered) firm following investment and is given by: $U = \left[\int_0^\infty \lambda' e^{-\lambda' s} \int_0^s e^{-rt}(1-\tau)ex \cdot X(t)dtds\right] = \frac{(1-\tau)ex \cdot X}{r-\mu+\lambda'}$, where $\lambda' = \lambda - k$ denotes the ESG risk remaining after investment.[3]

In line with the theoretical prediction of Hackbarth et al. (2007) regarding the optimality of debt seniority with respect to market debt, we assume that bank debt is senior to market debt in case of bankruptcy. This assumption is supported by empirical evidence by Rauh and Sufi (2010). Thus, in the event of bankruptcy, bank lenders recover the minimum of the perpetual value of coupons and the liquidation value of the firm, so that their recovery value in case of default, $R_b(v_t)$ is given by

$$R_b(v_t) = min\left\{\frac{b}{r+\lambda'}, L(v_t)\right\} \qquad (3)$$

The junior market debt holders will only recover something in case senior bank lenders are fully paid off at bankruptcy. Thus, their recovery value, $R_c(v_t)$ is given by

$$R_c(v_t) = max\left\{L(v_t) - \frac{b}{r+\lambda'}, 0\right\} \qquad (4)$$

[3] An alternative derivation of the above is through solving the differential equation of U. First, define $v_t = ex\, X_t$. Using Ito's lemma, v_t follows the same process as (1). Using standard arguments, $U(v)$ satisfies the following differential equation: $rU(v) = (1-\tau)v + \mu X U'(v) + \frac{1}{2}\sigma^2 X^2 U''(v) - \lambda U(v)$. By applying the particular solution $U(v) = A_1 v + A_0$ we obtain $A_1 = \frac{(1-\tau)v}{r-\mu+\lambda'}$ and $A_0 = 0$ resulting in $U(v) = \frac{(1-\tau)v}{r-\mu+\lambda'}$, where one replaces for $v = exX$ to express this as a function of X.

If firm cash flows further deteriorate, default occurs at an optimally determined time, at the first passage time of the firm's cash flow, v_t through the endogenous bankruptcy threshold, v_d, from above.

To take into account the cost of a private workout, we introduce the probability of debt renegotiation failure denoted by $q \in (0,1)$, consistent with in Davydenko and Strebulaev (2007), Favara et al. (2012), Morellec et al. (2015), and Gan et al. (2022). The higher the probability of renegotiation failure, the higher the renegotiation cost. We assume renegotiation costs are borne by equityholders.

4. Model solution

We solve the model using a backward induction approach, starting with deriving all values after investment. We denote by $E_n(v; b_n, c)$, $B_n(v; b_n, c)$ and $C_n(v; b_n, c)$ the equity, bank debt and market debt values after debt restructuring respectively following investment. The values of equity, bank debt and market debt before debt restructuring following investment are denoted by $E_i(v; b, c)$, $B_i(v; b, c)$ and $C_i(v; b, c)$, respectively. Note that $v = ex\,X$ so that the expressions can readily be translated in terms of X. The value of equity before investment is denoted by $E_b(X)$.

4.1. After investment values

4.1.1. After debt restructuring

Following debt renegotiation, the firm pays a reduced coupon to the bank, b_n, and the full coupon c for the bond, and default when the firm cash flows reach from above the default threshold. The after-tax cash flow received by equityholders after debt restructuring is thus $(1-\tau)(v_t - b_n - c)$. To obtain the values of equity, bank debt and market debt after debt restructuring we follow standard arguments and solve ordinary differential equations subject to the boundary conditions (see Appendix A for details).

The values of $E_n(v; b_n, c)$, $B_n(v; b_n, c)$ and $C_n(v; b_n, c)$ of the equity, bank debt and market debt values after debt restructuring respectively following investment are given below:

$$E_n(v) = (1-\tau)\left(\frac{v}{r-\mu+\lambda'} - \frac{b_n+c}{r+\lambda'}\right) - \left[(1-\tau)\left(\frac{v_d}{r-\mu+\lambda'} - \frac{b_n+c}{r+\lambda'}\right)\right]\left(\frac{v}{v_d}\right)^{\beta_2'} \quad (5)$$

$$v_d = \frac{\beta_2'(r-\mu+\lambda')(b_n+c)}{(\beta_2'-1)(r+\lambda')} \quad (6)$$

$$C_n(v) = \frac{c}{r+\lambda'} - \left(\frac{c}{r+\lambda'} - R_c(v_d)\right)\left(\frac{v}{v_d}\right)^{\beta_2'} \tag{7}$$

$$B_n(v) = \frac{b_n}{r+\lambda'} - \left(\frac{b_n}{r+\lambda'} - R_b(v_d)\right)\left(\frac{v}{v_d}\right)^{\beta_2'} \tag{8}$$

Proof. See Appendix A.1.

The first term in equation (5) represents the expected present value of the after-tax cash flows net of the expected present value of the perpetual after-tax total coupon payment. The second term accounts for the adjustments in value by considering future default.

The first term in equation (7) represents the default-free debt value, while the second term represents the change in value due to future default. A similar interpretation applies to the case of bank debt in (8).

The default threshold is optimally selected by shareholders to maximize equity value and is given by the expression in equation (6). In terms of the original cash flows, since $v_d = ex\, X_d$, we have that $X_d = \frac{\beta_2'(r-\mu+\lambda')(b_n+c)}{(\beta_2'-1)(r+\lambda')ex}$.

4.1.2 Before debt restructuring

In this section we move one stage backwards, following investment but before debt restructuring, to obtain the equity, market debt and bank debt values at the time of investment.

The renegotiation of bank debt is modeled through a permanent coupon reduction (Moraux and Silaghi, 2014). In order for renegotiation to be successful the parties need to obtain a value from renegotiation that is at least as large as their outside options or reservation values. For bank creditors to accept renegotiation, the new bank debt value that they obtain under the reduced coupon needs to be at least as large as the current value of their debt with full coupon payments (which represents their reservation value).[4] When the equityholders have all bargaining power, i.e., $\eta = 1$, they will offer a reduced coupon such that bank debt value will remain the same under the new reduced coupon and creditors will be indifferent between accepting and rejecting the renegotiation offer. In general, when bank creditors also have some bargaining power, i.e., $\eta > 1$, the value that they obtain from renegotiation will be larger than their outside option.

[4] Indeed, if bank creditors refuse renegotiation, it is optimal for the equity holder to continue paying the full coupon (equity is positive above the default threshold), and not to default (the equity holder would get zero in default).

Formally, the reduced coupon will be optimally determined by the following condition: $B_n(b_n, v_n) = \eta B_n(b, v_n)$, where $B_n(b, v_n) = \frac{b}{r+\lambda'} - \left(\frac{b}{r+\lambda'} - R_b(v_b)\right)\left(\frac{v_n}{v_b}\right)^{\beta_2'}$ with $v_b = \frac{\beta_2'(r-\mu+\lambda')(b+c)}{(\beta_2'-1)(r+\lambda')}$ represents the value of bank debt at renegotiation under full coupon payments. The following provide the value of equity, market debt, and bank debt, respectively:

$$E_i(v) = (1-\tau)\left(\frac{v}{r-\mu+\lambda'} - \frac{b+c}{r+\lambda'}\right) - \left[(1-\tau)\left(\frac{v_n}{r-\mu+=\lambda'} - \frac{b+c}{r+\lambda'}\right) - (1-q)E_n(v_n)\right]\left(\frac{v}{v_n}\right)^{\beta_2'} \quad (9)$$

$$v_n = \frac{\beta_2'(r-\mu+\lambda')(b+c)}{(\beta_2'-1)(r+\lambda')} \quad (10)$$

$$C_i(v) = \frac{c}{r+\lambda'} - \left(\frac{c}{r+\lambda'} - (1-q)C_n(v_n) - qR_c(v_n)\right)\left(\frac{v}{v_n}\right)^{\beta_2'} \quad (11)$$

$$B_i(v) = \frac{b}{r+\lambda'} - \left(\frac{b}{r+\lambda'} - (1-q)B_n(v) - qR_b(v_n)\right)\left(\frac{v}{v_n}\right)^{\beta_2'} \quad (12)$$

Proof. See Appendix A.2.

The optimal renegotiation threshold v_n is optimally chosen by the equityholders to maximize initial equity value. Given the non-linearities involved, this equation has no closed-form solutions and is thus solved numerically. In line with Moraux and Silaghi (2014) and Silaghi (2018), we show in numerical simulations that the optimal renegotiation threshold is the threshold at which the firm would default in the absence of renegotiation, given by the expression in equation (10). Intuitively, equityholders want to postpone renegotiation as much as possible so that they maximize the coupon reduction.

4.2. Before investment values

We now move backwards to the first stage before investment, to obtain the equity value at time zero. Before investment, the ESG risk is given by λ and the firm is fully equity financed.

The equity value before investment is given as follows:

$$E_b(X) = (1-\tau)\left(\frac{X}{r-\mu+\lambda}\right) + \left[E_i(ex\ X_I) - \left(I - B_i(ex\ X_I) - C_i(ex\ X_I)\right) - (1-\tau)\left(\frac{X_I}{r-\mu+\lambda}\right)\right]\left(\frac{X}{X_I}\right)^{\beta_1} \quad (13)$$

The optimal investment threshold is determined through the smooth pasting condition:

$E_b'(X_I) = E_i'(X_I) + B_i'(X_I) + C_i'(X_I))$ (14)

Proof. See Appendix A.3.

4.3. Optimal capital structure and financing of investment costs

4.3.1. Optimal capital structure

Equityholders optimally choose the firm's capital structure policy, i.e., the mixture of bank and market debt to maximize the equity value just before the investment. The latter one, by the value-matching condition, equals the equity value after investment less the net contribution from the equityholders, $E_i(X_I) - (I - B_i(X_I) - C_i(X_I))$ (Morellec et al., 2015). This coincides with maximizing the total value of the firm *(V)* at $X = X_I$ where $V_i(X) = E_i(X) + B_i(X) + C_i(X)$. In sum, we need to solve:

$$(b, c) = argmax_{b,c} V_i(X) \qquad (14)$$

Note that b and c can be solved numerically ensuring that the smooth pasting condition for optimal investment timing (eq.14) is also satisfied.

4.3.2. Debt financing constraints and financing of investment costs

Alternatively, we also consider the case of exogenously imposed debt financing constraints. In this case, the equityholders need to select the optimal coupon levels and investment trigger subject to the constraint $B_i(X_I) + C_i(X_I) \leq D_{max}$, where D_{max} represents the exogenously imposed debt financing constraint. That is, the level of bank debt and market debt is constrained at a certain D_{max} level, so that the firm has access to debt issuance only up to the amount D_{max}. These constraints might be justified, for example, by risk-shifting incentives of the equityholders causing lenders to be reluctant to lend beyond a certain amount. Note that in the unconstrained case, the total optimal debt level might exceed the investment cost, which means that the excess cash would be distributed to equityholders as dividend. This subsection can be useful for most practical applications in which debt is lower or equal to the investment cost.

The maximum debt level, D_{max}, can be assumed to be proportional to the investment cost as in Koussis and Martzoukos (2012) or Shibata and Nishihara (2015). Morellec and Shurhoff (2011) considered a special case of this constraint where the level of debt is constrained to be equal to the level of investment. In their model, the firm could finance the investment with a single source of financing, either debt or equity. More generally, we capture the broader effect of various debt financing constraints relative to the optimal debt level of the firm, that is, relative to the unconstrained case. Shibata and Nishihara (2015) consider the effect of debt financing constraints on investment timing and debt structure by separately considering the effects of constraints on either bank or public debt. In contrast, in our model, we consider the effect of financing constraints on how a firm times its investment when there are two sources of financing, bank and public debt.

5. Numerical analysis and model predictions

In order to gain further insights, we proceed with numerical simulations. We use the following parameter values: $X = 10$, $r = 0.05$, $\mu = 0.01$, $\tau = 0.2$, $\alpha = 0.5$, $\sigma = 0.15$, $\lambda = 0.05$ and $ex = 1.1$ which are along the lines of other standard real options frameworks (see for example, Hackbarth and Mauer, 2012). We assume that the investment cost $I = 100$, and we initially consider full bargaining power for equity holders, $\eta = 1$, and zero probability of renegotiation failure, $q = 0$.

5.1. ESG risk and the impact on firm's capital structure

First, we investigate the impact of higher ESG risk on firm value, the timing of exercise of growth options and debt structure assuming that firms cannot control ESG risk. This analysis shows the expected impact of ESG risks that are priced but cannot be reduced through active CSR firm policies.

Figure1 shows the results. The results are summarized in the following proposition.

Proposition 1. Higher levels of ESG risk result in lower firm value, delays in firm's exercise of growth opportunities, higher levels of leverage when the firm exercises its investment options and a lower proportion of bank debt compared to public debt. Higher ESG risk increases credit risk through the increase in renegotiation and default triggers.

The mechanism through which higher ESG risk increases leverage ratios is complex. Following investment in the growth option, higher ESG risk effectively raises the discount rate applied to future costs, including debt coupon payments. Simultaneously, it imposes a higher "dividend yield" effect, which reduces anticipated revenue. Overall, the negative impact of ESG risk on the expected present value of cash flows outweighs the positive discounting effects on costs. As a result, the anticipated present value of cash flows from the investment declines, prompting the firm to delay investment until higher revenue levels are achieved.

These delays in investment allow the firm to issue higher optimal coupons for both public debt and bank debt due to higher cash flow levels when the investment eventually occurs. Although the optimal coupon of bank debt increases with ESG risk, the present value of the future coupons received by bank lenders decreases with ESG risk since the higher effective discount rate effect dominates. Moreover, by increasing the coupon levels, a higher ESG risk also increases both the renegotiation and the default thresholds. Nevertheless, since investment is postponed for higher ESG risk (the investment threshold rises), the expected timing of hitting renegotiation and default triggers once investment has taken place decreases with ESG risk (an effect further potentiated through the impact of ESG risk on auxiliary parameter β_2). Additionally, a higher effective discount rate driven by a higher ESG risk also has an important effect on the present value of the recovery in case of bankruptcy which decreases with ESG risk. Overall, the lower present value of bank coupons and the lower recovery value effects dominate, and we find that bank debt decreases with ESG risk.

Since bank debt has a significant advantage compared to public debt as it allows minimizing bankruptcy costs through renegotiation, firms will leverage bank debt as much as they can before turning to market debt. Hence, the optimal coupon on bank debt is very large compared to the one of public debt. Unlike for bank debt, in the case of public debt, the positive effect of having a higher coupon with increased ESG risk dominates the negative effect of a higher effective discount rate, since public debt coupon levels are quite low. Thus, the present value of the public debt coupons increases with ESG risk. Moreover, the probability of reaching default decreases when ESG risk increases. Hence, public debt value increases with ESG risk. Overall, since firms use bank debt to a much larger extent, total debt value decreases with ESG risk. However, firm value at investment decreases at a higher pace with ESG risk since equity value is also negatively affected by ESG risk. Hence, firm leverage increases with high ESG risk. This dynamic in which bank debt decreases in response to higher ESG risk, while public debt rises, ultimately lowers the proportion of bank debt in the firm's overall debt structure.

We now consider firms' option to adjust their ESG risk through investment in ESG assets. We assume a complete information setting where all investors are aware of the true reduction k of a firm's ESG investment. Figure 2 summarizes the results showing how a firm may time its investment in ESG depending on the expected reduction in ESG risk. As a corollary to proposition 1 we thus have the following:

Corollary 1. In a complete information framework, an investment causing a higher reduction in ESG risk results in earlier investment, lower levels of leverage, a higher proportion of bank financing and lower levels of credit risk.

Proposition 1 and Corollary 1 explain the empirical evidence in Newton et al. (2024) who show that firms with higher ESG reputation risks prefer public bonds over bank loans. Our theoretical framework aligns well showing that firms with high ESG risk avoid bank loans to avoid renegotiation risk damage linked to ESG missteps. Our analysis also explains the empirical evidence provided by Asimakopoulos et al. (2023) who find that firms that become ESG-rated implying a reduction in investors' ESG risk exposure reduce their target leverage ratios, increase the use of bank financing and reduce the use of bond financing. They suggest that ESG ratings act as a signalling mechanism to lenders, reducing information asymmetry. However, our analysis reveals that even in a complete information setting, ESG risk reduction results in lower leverage but also a higher proportion of bank financing.

In Appendix B, we present sensitivity of our model parameters providing model predictions regarding investment timing in ESG, renegotiation and bankruptcy timing, firm value, leverage ratios and the proportion of bank versus public financing. The following proposition summarizes the empirical predictions of the model in a complete information setting focusing on the effects on investment in timing in ESG and debt structure.

Proposition 2a (Investment timing in ESG). In a complete information setting, investment in ESG reduction is accelerated for lower volatility (σ), lower probability of renegotiation failure (q), lower bankruptcy costs (a), higher growth rate of revenues (μ), lower investment cost (I), higher tax rates (τ), higher expansion factor (ex) and lower risk-free rate (r). Higher renegotiation power of debt holders (η) does not affect the timing of ESG investments.

Proposition 2b (Debt structure). In a complete information setting, investment in ESG reduction is associated with lower leverage ratios and a higher proportion of bank financing for higher volatility (σ), higher probability of renegotiation failure (q), lower growth rate of revenues (μ), higher investment cost (I), lower tax rate (τ), and a lower risk-free rate (r). Higher renegotiation power of debt holders does not affect leverage ratios (η) but increases the proportion of bank financing. A higher growth expansion factor (ex) does not affect leverage ratios and the proportion of debt financing.

5.2. The impact of financing constraints on ESG investment timing and debt structure.

When the debt financing constraints becomes binding, $B_i(X_I) + C_i(X_I) \leq D_{max}$, the firm needs to reduce the investment trigger and/or the coupon levels such that the constraint is satisfied, since reducing either the investment trigger or the coupon level decreases debt value. Figure 3 illustrates the results of applying debt financing constraints. Starting from the unconstrained scenario where the firm utilizes 100% of its optimal debt level, we observe that when the firm faces minor debt constraints (e.g., 80%-90% of optimal debt), it sacrifices part of its investment flexibility by accelerating investment to maintain the highest possible coupon levels (and retain significant tax shields) while still satisfying the constraint. When constraints become stricter, the tax shields lose significance. Consequently, the firm places greater emphasis on increasing the value of the option to wait, leading to delayed timing. Our results confirm the U-shaped pattern of the investment trigger with respect to the debt constraints from Koussis and Martzoukos (2012) and Shibata and Nishihara (2015) for the case of mixed debt structure.

Importantly, there is a substantial shift in the debt structure: in the unconstrained case, the percentage of bank financing is 85%, whereas under minor constraints, the firm utilizes 93% bank debt for 90% of its debt capacity and 100% bank debt when the constraints become more binding at 70%-80% of the debt capacity. As the constraint becomes significant, the firm prioritizes timing flexibility, postponing investment to achieve higher gains from the option to wait and time its investment. In this region, the percentage of bank debt financing declines and returns to levels similar to those in the unconstrained case when the constraints become severe. Proposition 3 summarizes the findings on the impact of financing constraints.

Proposition 3. The timing of ESG investment follows a U-shaped pattern as a function of debt financing constraints. The firm accelerates renegotiation and faces an increased likelihood of bankruptcy under less restrictive debt constraints. Conversely, the percentage of bank debt financing exhibits an inverse U-shaped relationship with debt financing constraints.

Proposition 3 indicates that when firms face small to moderate debt constraints relative to unconstrained debt levels, they are more likely to accelerate ESG investments. However, as these constraints become increasingly restrictive, firms tend to postpone ESG investments. Our results are consistent with prior literature (see Koussis and Martzoukos, 2012, and Shibata and Nishihara, 2015), extending their insights to the case of two possible debt sources: bank and public debt. However, our model predictions differ from those of Morellec et al. (2015), who focus on bank credit supply constraints driven by search costs in finding informed private lenders and find that a lower supply of credit always delays investment.

Our model can accommodate scenarios where a firm faces constraints on only one source of financing—either bank or public debt financing. This flexibility is particularly relevant for many small or private firms that may lack access to public markets, making constraints on public debt financing significant and easily captured within our framework.

Furthermore, our findings reveal that milder debt financing constraints increase the risk of renegotiation and bankruptcy due to greater reliance on debt financing. The analysis also shows that moderate constraints encourage greater use of bank debt financing; however, as constraints become more severe, the proportion of bank debt in the firm's capital structure declines.

Notably, constraints imposed solely to cover investment costs have significant implications for the timing of growth-ESG investments and the firm's debt structure. Within this range of debt constraints—approximately 40% of the unconstrained level in our baseline parameters—firms significantly delay ESG investments and become substantially more dependent on bank debt.

6. Conclusion

In conclusion, this study highlights the significant impact of ESG risk on firms' investment decisions, leverage and debt structure. Our contingent claim model demonstrates that higher ESG risk leads to delays in exercising growth options, increased leverage at the point of investment, and a shift from bank debt to public debt financing. These findings are consistent with empirical evidence showing that firms with higher ESG risks tend to favour public bonds over bank loans. Moreover, our model reveals that firms are more likely to accelerate ESG investments in environments with lower renegotiation failure risk, lower bankruptcy costs, higher tax rates, and lower risk-free rates, providing valuable insights for policymakers aiming to promote sustainable investment practices.

Additionally, the study uncovers the nuanced relationship between debt financing constraints and ESG investment timing. We find a U-shaped pattern where firms accelerate ESG investments under mild constraints but delay them as constraints become more severe. This dynamic also influences the firm's debt structure, with moderate constraints increasing reliance on bank debt, while stricter constraints reduce its proportion in favour of public debt. Notably, when constraints are imposed solely to cover investment costs, firms significantly delay ESG investments and rely more heavily on bank financing. These insights emphasize the importance of regulatory policies and market conditions in shaping firms' ESG investment strategies and capital structure decisions, offering practical implications for enhancing corporate sustainability efforts.

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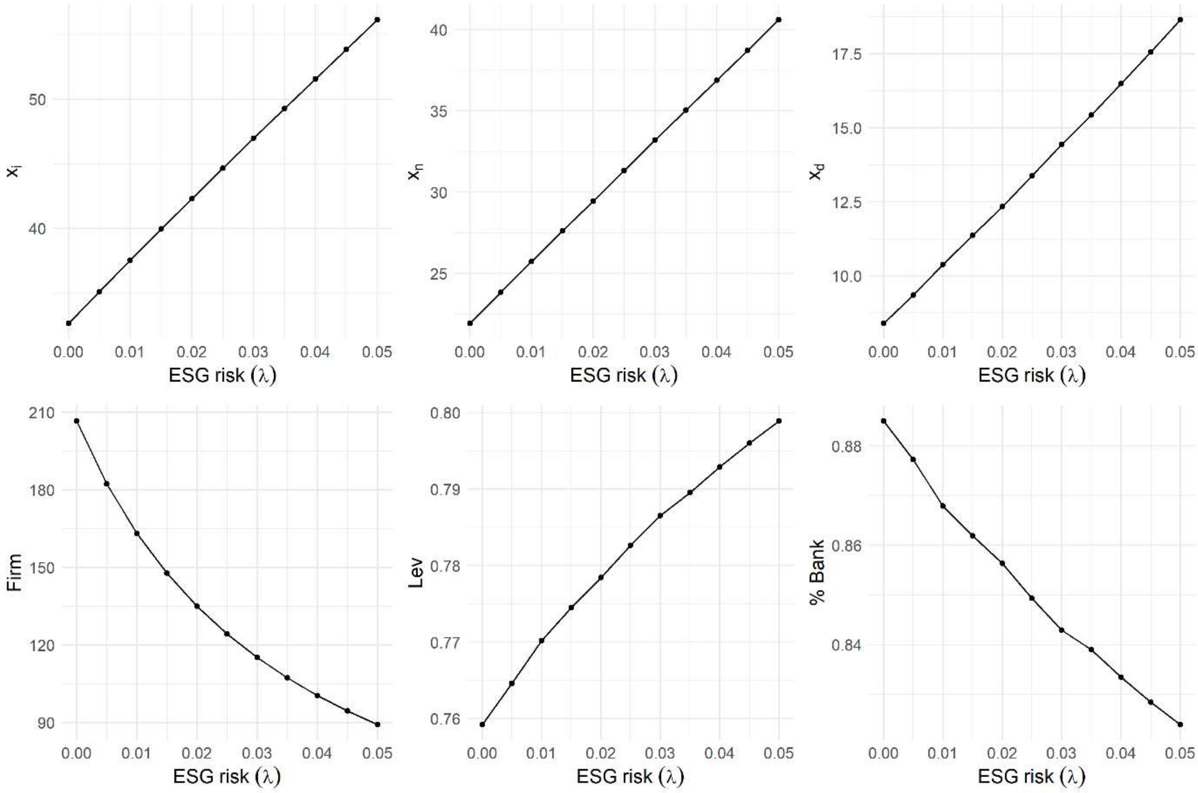
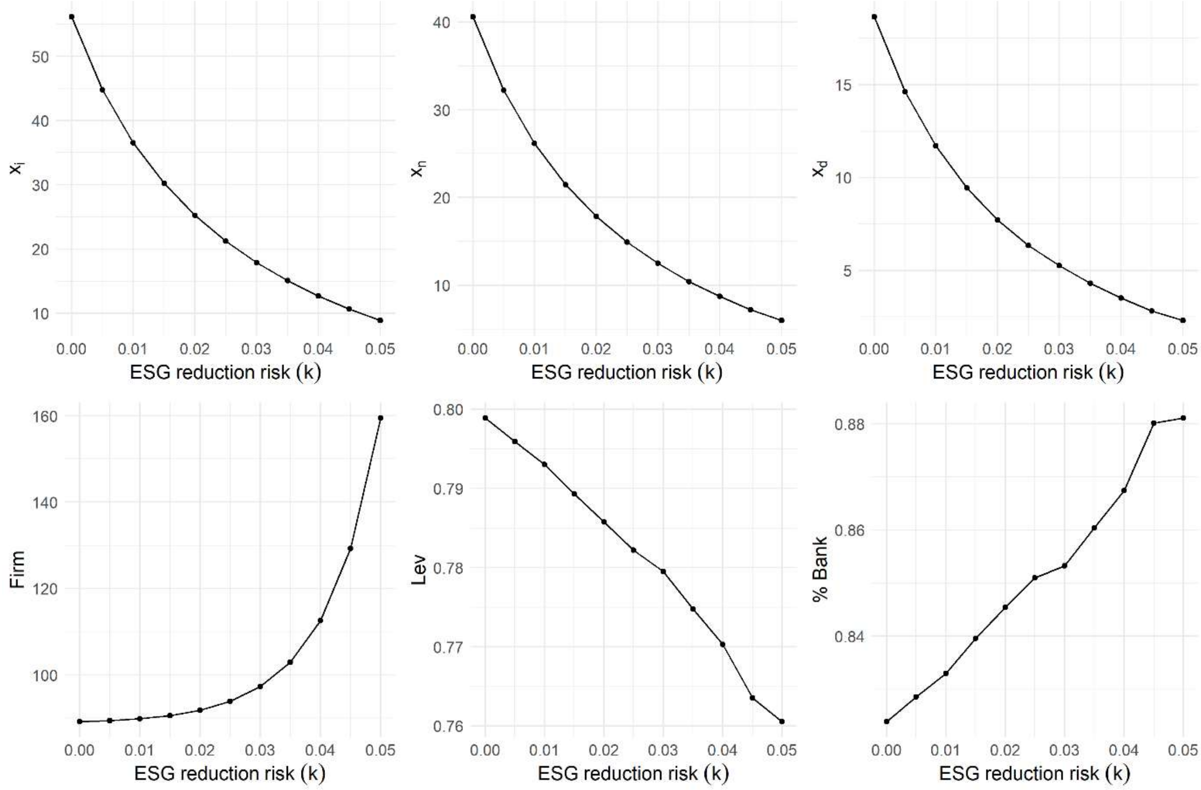
Figure 1. The effect of ESG risk



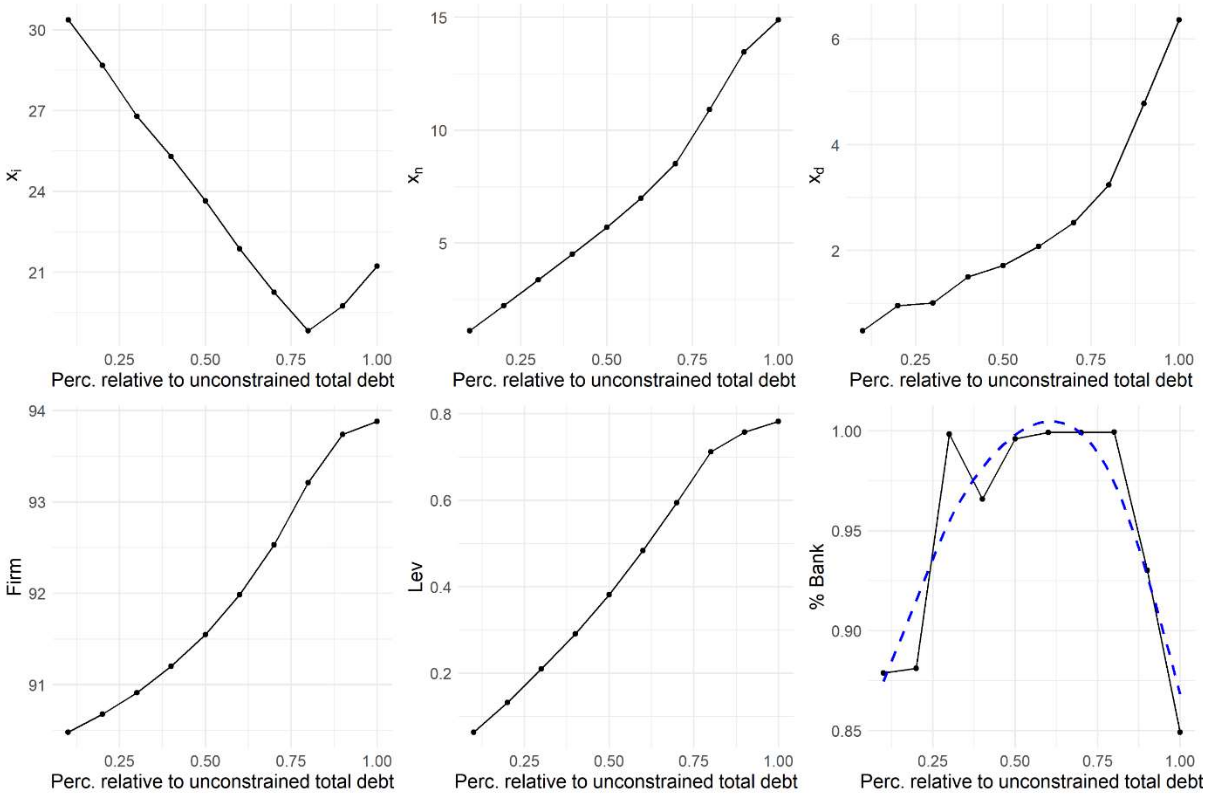
Notes: $x = 10, r = 0.05, \tau = 0.2, \mu = 0.01, \sigma = 0.15, \alpha = 0.5, ex = 1.1., I = 100, \eta = 1, q = 0$. Sensitivity to ESG risk (λ). Reduction in ESG risk k=0.

Fig.2. The effect of reduction in ESG risk (k)



Notes: $x = 10, r = 0.05, \tau = 0.2, \mu = 0.01, \lambda = 0.05, \sigma = 0.15, \alpha = 0.5, ex = 1.1., I = 100, \eta = 1, q = 0$. Reduction in ESG risk k between 0-0.02. Firm refers to equity value at t = 0.

Figure 3. Constraints on debt financing



Notes: $x = 10, r = 0.05, \tau = 0.2, \mu = 0.01, \lambda = 0.05, \sigma = 0.15, \alpha = 0.5, ex = 1.1., I = 100, \eta = 1, q = 0$. Reduction in ESG risk k between 0.025. Firm refers to equity value at t = 0. Perc. of max debt capacity is the percentage of maximum debt capacity which for this parameter is 264.33 which exists in the unconstrained case with bank debt at 224.46 and public debt at 39.87. The unconstrained case is depicted in the figure at percentage of debt financing being 100% of debt capacity. The blue line in last panel depicts a smoother function to illustrate the overall shape of the relation. Coupon increments used for optimizing coupons are of increments of 0.01.

Appendix A: Detailed derivations for complete information setting

A.1. Security values following investment and restructuring

Define $\lambda' = \lambda - k$ and $v_t = ex\,X$. Liquidation following investment is then $L(v_t) = (1-\alpha)\frac{(1-\tau)v_t}{r-\mu+\lambda'}$, bank lenders recover the minimum of the perpetual value of coupons and the liquidation value of the firm, so that their recovery value in case of default, $R_b(v_t)$ is given by $R_b(v_t) = min\left\{\frac{b}{r+\lambda'}, L(v_t)\right\}$. Junior market debt holders $R_c(v_t)$ is given by $R_c(v_t) = max\left\{L(v_t) - \frac{b}{r+\lambda'}, 0\right\}$.

The after-tax cash flow received by equityholders after debt restructuring is $(1-\tau)(v_t - b_n - c)$. The equity value after restructuring $E_n(v)$, assuming that the ESG risk has not yet materialized, satisfies the following ordinary differential equation:

$$(r+\lambda')E_n(v) = (1-\tau)(v - b_n - c) + \mu X E_n'(v) + \frac{1}{2}\sigma^2 X^2 E_n''(v) \qquad \text{(A1)}$$

The solution is of the following form:

$$E_n(v) = (1-\tau)\left(\frac{v}{r-\mu+\lambda'} - \frac{b_n+c}{r+\lambda'}\right) + A_1 v^{\beta_1'} + A_2 v^{\beta_2'} \qquad \text{(A2)}$$

with unknown constants A and B, and $\beta_1' > 0$ and $\beta_2' < 0$ given by:

$$\beta_1' = \frac{1}{2} - \frac{\mu}{\sigma^2} + \sqrt{\left(\frac{\mu}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2(r+\lambda')}{\sigma^2}} > 1 \qquad \text{(A3a)}$$

$$\beta_2' = \frac{1}{2} - \frac{\mu}{\sigma^2} - \sqrt{\left(\frac{\mu}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2(r+\lambda')}{\sigma^2}} < 0 \qquad \text{(A3b)}$$

Equation (A1) is solved by using the following boundary conditions:

$$\lim_{v\to\infty} \frac{E_n}{v} < +\infty \qquad \text{(A4a)}$$

$$\lim_{v\to v_d} E_n(v) = 0 \qquad \text{(A4b)}$$

Equation (A4a) represents the standard no-bubble condition, while equation (A4b) is the value matching condition at v_d. Note that $v_d = ex\,X_d$ when expressed in the terms of X. From equation (A4a) we obtain that $A_1 = 0$, while from equation (A4b) we obtain that $A_2 = -\left[(1-\tau)\left(\frac{v_d}{r-\mu+\lambda'} - \frac{b_n+c}{r+\lambda'}\right)\right]\left(\frac{1}{v_d}\right)^{\beta_2}$.

Plugging in the expressions for A_1 and A_2 into equation (A2) and replacing where $v = ex\,X$ we have that the equity value after restructuring is given by:

$$E_n(v) = (1-\tau)\left(\frac{v}{r-\mu+\lambda'} - \frac{b_n+c}{r+\lambda'}\right) - \left[(1-\tau)\left(\frac{v_d}{r-\mu+\lambda'} - \frac{b_n+c}{r+\lambda'}\right)\right]\left(\frac{v}{v_d}\right)^{\beta_2'} \tag{A5}$$

The optimal default threshold is determined through the smooth pasting condition:

$$E_n'(v_d) = 0, \tag{A6}$$

which results in the following closed-form expression for the default threshold in terms of v:

$$v_d = \frac{\beta_2'(r-\mu+\beta_1')(b_n+c)}{(\beta_2'-1)(r+\lambda')} \equiv ex\, X_d \tag{A5}$$

The value of equity expressed in terms of X is thus:

$$E_n(exX) = (1-\tau)\left(\frac{exX}{r-\mu+\lambda'} - \frac{b_n+c}{r+\lambda'}\right) - \left[(1-\tau)\left(\frac{ex\, X_d}{r-\mu+\lambda'} - \frac{b_n+c}{r+\lambda'}\right)\right]\left(\frac{X}{X_d}\right)^{\beta_2'} \tag{A6}$$

Note that $X_d = \frac{\beta_2'(r-\mu+\lambda')(b_n+c)}{(\beta_2'-1)(r+\lambda')ex}$.

The market debt value after renegotiation $C_n(v)$ satisfies the following ordinary differential equation:

$$(r+\lambda')C_n(v) = c + \mu X C_n'(v) + \frac{1}{2}\sigma^2 X^2 C_n''(v) \tag{A7}$$

The previous equation is solved using the following boundary conditions:

$$\lim_{v\to\infty} C_n(v) = \frac{c}{r+\lambda'} \qquad \text{(A8a)}$$

$$\lim_{v\to v_d} C_n(v) = R_c(v_d) \qquad \text{(A8b)}$$

These conditions are intuitive. When the firm's cash flow is sufficiently large, the market debt is essentially risk-free (the standard no-bubble condition). The value matching condition implies that in case of bankruptcy, market debt is junior with respect to bank debt, and obtains the recovery value $R_c(v_d)$.

Solving equation (A6) subject to the boundary conditions (A8a) and (A8b), we obtain:

$$C_n(v) = \frac{c}{r+\lambda'} - \left(\frac{c}{r+\lambda'} - R_c(v_d)\right)\left(\frac{X}{X_d}\right)^{\beta_2'} \tag{A8}$$

and expressing in terms of X, we obtain that the market debt value after restructuring is given by:

$$C_n(ex\, X) = \frac{c}{r+\lambda'} - \left(\frac{c}{r+\lambda'} - R_c(ex\, X_d)\right)\left(\frac{X}{X_d}\right)^{\beta_2'} \tag{A9}$$

The bank debt value after renegotiation $B_n(v)$ satisfies the following ordinary differential equation:

$$(r+\lambda')B_n(v) = b_n + \mu X B_n'(v) + \frac{1}{2}\sigma^2 X^2 B_n''(v) \tag{A10}$$

Equation (A9) is solved using the following boundary conditions:

$$\lim_{v\to\infty} B_n(v) = \frac{b_n}{r+\lambda'} \qquad \text{(A11a)}$$

$$\lim_{v\to v_d} B_n(v) = R_b(v_d) \quad \text{(A11b)}$$

Solving equation (A10) subject to the boundary conditions (A11a) and (A11b) we obtain that the bank debt value after restructuring is given by:

$$B_n(v) = \frac{b_n}{r+\lambda'} - \left(\frac{b_n}{r+\lambda'} - R_b(v_d)\right)\left(\frac{X}{X_d}\right)^{\beta_2'} \tag{A11}$$

Expressing in terms of X, we obtain:

$$B_n(ex\,X) = \frac{b_n}{r+\lambda'} - \left(\frac{b_n}{r+\lambda'} - R_b(ex\,X_d)\right)\left(\frac{X}{X_d}\right)^{\beta_2'} \tag{A12}$$

A.2. Security values following investment and before restructuring

We now derive the bank debt value after investment but before restructuring. Knowing that bank lenders obtain the full coupon payment b before renegotiation and before the realization of ESG risk, the bank debt value before restructuring satisfies the following ODE:

$$(r+\lambda')B_i(v) = b + \mu X B_i'(v) + \frac{1}{2}\sigma^2 X^2 B_i''(v) \tag{A13}$$

Equation (A12) is solved using the following boundary conditions:

$$\lim_{v\to\infty} B_i(v) = \frac{b}{r+\lambda'} \qquad \text{(A14a)}$$

$$\lim_{v\downarrow v_n} B_i(v) = \lim_{v\uparrow v_n}(1-q)B_n(v) + qR_b(v) \quad \text{(A14b)}$$

Equation (A14a) is the standard no-bubble condition. The value matching condition (A14b) implies that at renegotiation, bank lenders obtain a new debt value in case renegotiation is successful, which occurs with probability q and obtain the recovery value $R_b(v)$ in case renegotiation fails. We thus obtain that the bank debt value before restructuring,

We thus obtain that the bank debt value before restructuring as:

$$B_i(v) = \frac{b}{r+\lambda'} - \left(\frac{b}{r+\lambda'} - (1-q)B_n(v_n) - qR_b(v_n)\right)\left(\frac{v}{v_n}\right)^{\beta_2'} \tag{A15}$$

Expressed in terms of X, we obtain:

$$B_i(ex\,X) = \frac{b}{r+\lambda'} - \left(\frac{b}{r+\lambda'} - (1-q)B_n(ex\,X_n) - qR_b(ex\,X_n)\right)\left(\frac{X}{X_n}\right)^{\beta_2'} \tag{A16}$$

The equity value after investment before restructuring satisfies the following ODE:

$$(r+\lambda')E_i(v) = (1-\tau)(v-b-c) + \mu X E_i'(v) + \frac{1}{2}\sigma^2 X^2 E_i''(v), \qquad \text{(A17)}$$

with the following boundary conditions:

$$\lim_{v\to\infty} \frac{E_i}{v} < +\infty \qquad \text{(A18a)}$$

$$\lim_{v\downarrow v_n} E_i(v) = (1-q)\,E_n(v) \qquad \text{(A18b)}$$

The equity value before restructuring is therefore given by:

$$E_i(v) = (1-\tau)\left(\frac{v}{r-\mu+\lambda'} - \frac{b+c}{r+\lambda'}\right) - \left[(1-\tau)\left(\frac{v_n}{r-\mu+\lambda'} - \frac{b+c}{r+\lambda'}\right) - (1-q)E_n(v_n)\right]\left(\frac{v}{v_n}\right)^{\beta_2'} \text{(A19)}$$

The renegotiation threshold v_n is optimally chosen by equityholders to maximize the equity value (Fan and Sundaresan, 2000). Given the non-linearities involved, this equation is solved numerically, since there are no closed-form solutions. In numerical simulations we show that the optimal renegotiation threshold is the threshold at which the firm would default in the absence of renegotiation, in line with Moraux and Silaghi (2014) and Silaghi (2018): [5]

$$v_n = \frac{\beta_2'(r-\mu+\lambda')(b+c)}{(\beta_2'-1)(r+\lambda')} \qquad \text{(A19)}$$

Note that $v_n = exX_n$ based on the variable X.

The equity value before restructuring expressed in terms of X is:

$$E_i(exX) = (1-\tau)\left(\frac{exX}{r-\mu+\lambda'} - \frac{b+c}{r+\lambda'}\right) - \left[(1-\tau)\left(\frac{exX_n}{r-\mu+\lambda'} - \frac{b+c}{r+\lambda'}\right) - (1-q)E_n(exX_n)\right]\left(\frac{X}{X_n}\right)^{\beta_2} \text{(A20)}$$

Finally, the market debt value before restructuring satisfies the following ODE:

$$(r+\lambda')C_i(v) = c + \mu X C_i'(v) + \frac{1}{2}\sigma^2 X^2 C_i''(v)\,, \qquad \text{(A21)}$$

subject to the following boundary conditions:

$$\lim_{v\to\infty} C_i(v) = \frac{c}{r+\lambda'} \qquad \text{(A22a)}$$

[5] Moraux and Silaghi (2014) and Silaghi (2018) provide an analytical proof that equity value is decreasing in the renegotiation threshold, so that it is optimal for equityholders to postpone renegotiation as much as possible, until the default threshold that depends on the original coupons, $b+c$ (and default is postponed to a new threshold that depends on the reduced bank coupon and the original bond coupon, b_n+c). In our case, since we have both market debt and bank debt, an analytical proof is not feasible.

$$\lim_{v\downarrow v_n} C_i(X) = \lim_{v\uparrow v_n}(1-q)C_n(v) + qR_c(v) \quad \text{(A22b)}$$

The market debt value is therefore given by:

$$C_i(v) = \frac{c}{r+\lambda'} - \left(\frac{c}{r+\lambda'} - (1-q)C_n(v_n) - qR_c(v_n)\right)\left(\frac{v}{v_n}\right)^{\beta_2'} \quad \text{(A23)}$$

Expressed in terms of X we obtain:

$$C_i(exX) = \frac{c}{r+\lambda'} - \left(\frac{c}{r+\lambda'} - (1-q)C_n(exX_n) - qR_c(exX_n)\right)\left(\frac{X}{X_n}\right)^{\beta_2'} \quad \text{(A24)}$$

A.3. Security values before investment

The equity value before investment satisfies the following ordinary differential equation:

$$(r+\lambda)E_b(X) = (1-\tau)X + \mu X E_b'(X) + \frac{1}{2}\sigma^2 X^2 E_b''(X) \quad \text{(A25)}$$

The solution is of the following form:

$$E_b(X) = (1-\tau)\left(\frac{X}{r-\mu+\lambda}\right) + A_{11}X^{\beta_1} + A_{22}X^{\beta_2} \quad \text{(A26)}$$

Equation (10) is solved by using the following boundary conditions:

$$\lim_{X\to X_I} E_b(X) = E_i(exX_I) - (I - B_i(exX_I) - C_i(\,exX_I)) \quad \text{(A27a)}$$

$$\lim_{X\to 0} E_b(X) = 0 \quad \text{(A27b)}$$

Using equation (A27b) we obtain that $A_{22} = 0$ and using (A26a) we obtain that $A_{11} = \left[E_i(exX_I) - \left(I - B_i(exX_I) - C_i(exX_I)\right) - (1-\tau)\left(\frac{X_I}{r-\mu+\lambda}\right)\right] X_I^{-\beta_1}$.

Thus, we obtain the equity value before investment as follows:

$$E_b(X) = (1-\tau)\left(\frac{X}{r-\mu+\lambda}\right) + \left[E_i(exX_I) - \left(I - B_i(exX_I) - C_i(exX_I)\right) - (1-\tau)\left(\frac{X_I}{r-\mu+\lambda}\right)\right]\left(\frac{X}{X_I}\right)^{\beta_1} \quad \text{(A28)}$$

The optimal investment threshold is determined through the smooth pasting condition:

$$\left.\frac{\partial E_b(X)}{\partial X}\right|_{X=X_I} = \left.\frac{\partial E_i(ex\,X)}{\partial X}\right|_{X=X_I} + \left.\frac{\partial B_i(ex\,X)}{\partial X}\right|_{X=X_I} + \left.\frac{\partial C_i(X)}{\partial X}\right|_{X=X_I}$$

(A29)

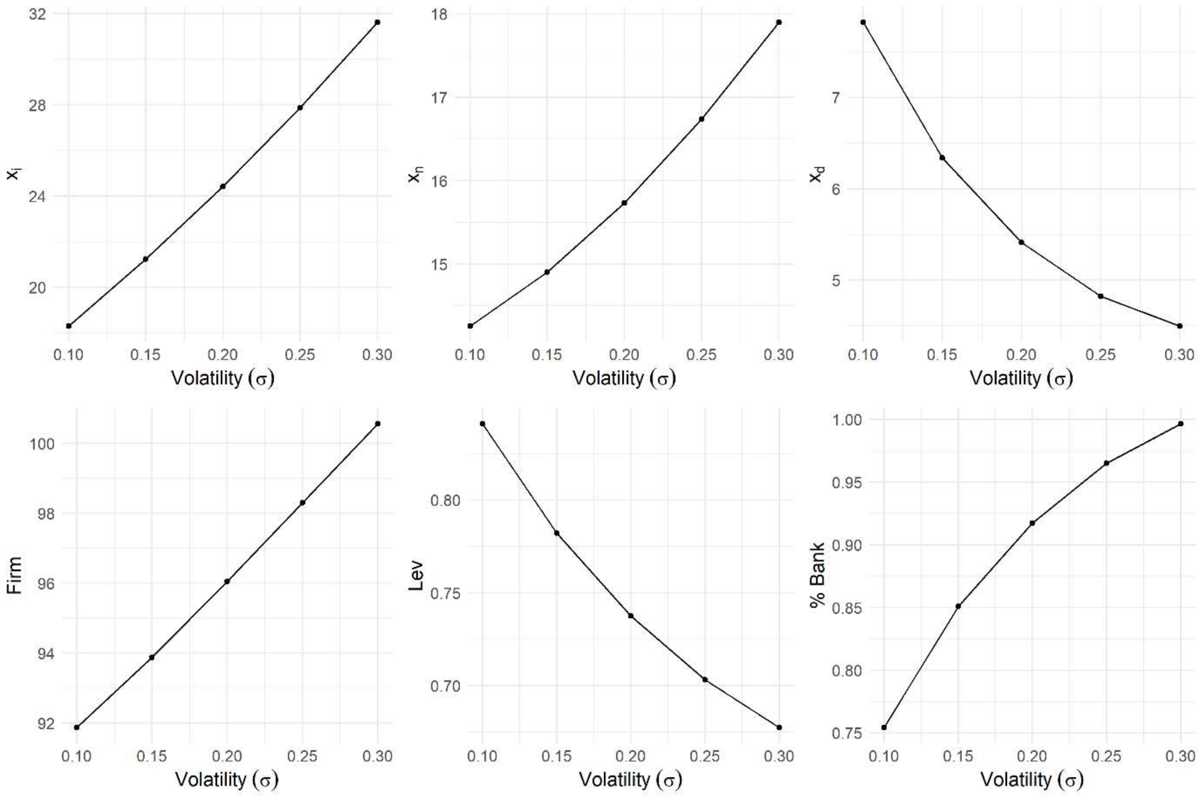
Note that in (A29), all expressions in $E_i(.)$, $B_i(.)$ and $C_i(.)$ are evaluated with respect to X using expressions (A20), (A16) and (A24) respectively. We thus obtain that the smooth pasting condition is given by:

$$\frac{1-\tau}{r-\mu+\lambda}+\frac{\beta_1}{X_I}\left[v_i(X_I)-I-\frac{(1-\tau)X_I}{r-\mu+\lambda}\right]=\frac{(1-\tau)ex}{r-\mu+\lambda'}-\frac{\beta_2'}{X_I}\left[\frac{(1-\tau)ex\quad n}{r-\mu+\lambda'}+\frac{\tau(b+c)}{r+\lambda'}-(1-q)E_n(exX_n)-\right.$$

$$\left.(1-q)B_n(exX_n)-(1-q)C_n(exX_n)-qR_b(exX_n)-qR_c(exX_n)\right]\left(\frac{X}{X_n}\right)^{\beta_2'} \quad \text{(A30)}$$

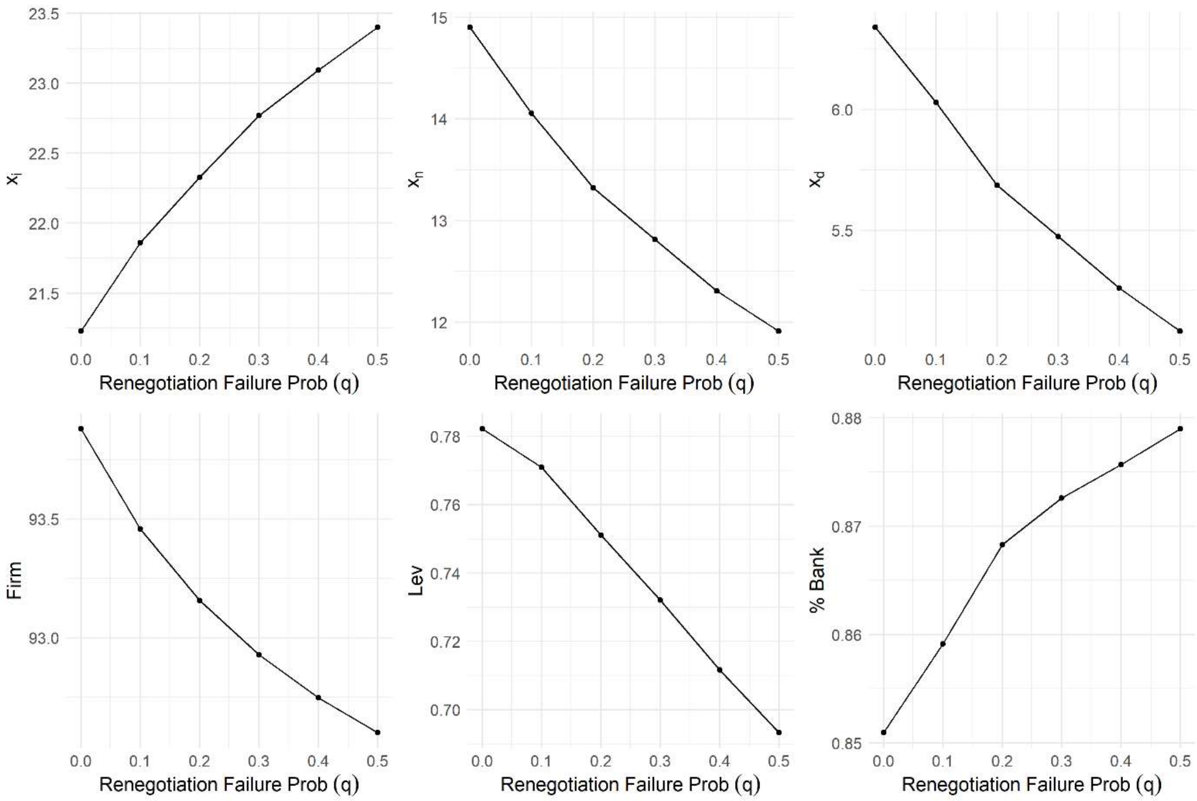
Appendix B: Sensitivity analysis to model parameters

Figure A1. The effect of volatility risk (σ)



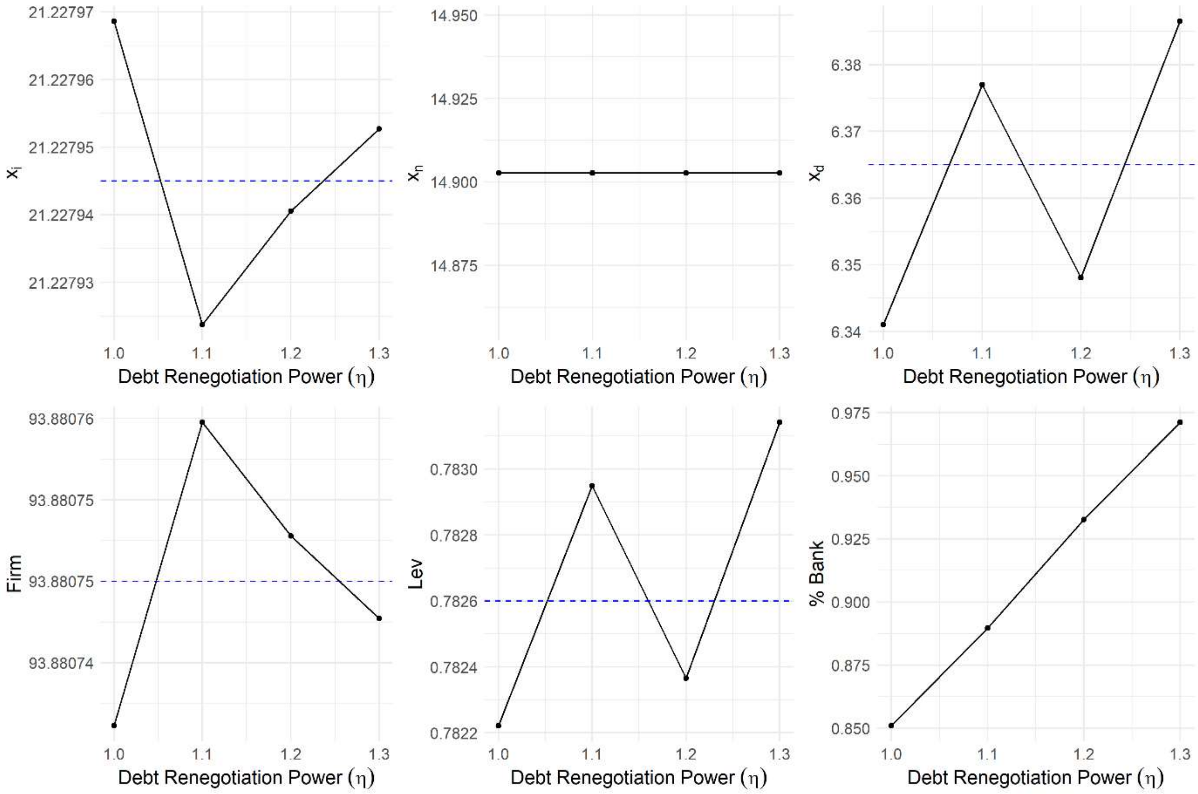
Notes: $x = 10, r = 0.05, \tau = 0.2, \mu = 0.01, \lambda = 0.05, \sigma = 0.15, \alpha = 0.5, ex = 1.1., I = 100, \eta = 1, q = 0$. Reduction in ESG risk $k = 0.025$. Firm refers to equity value at t = 0.

Figure A2. The effect of risk of renegotiation failure (q).



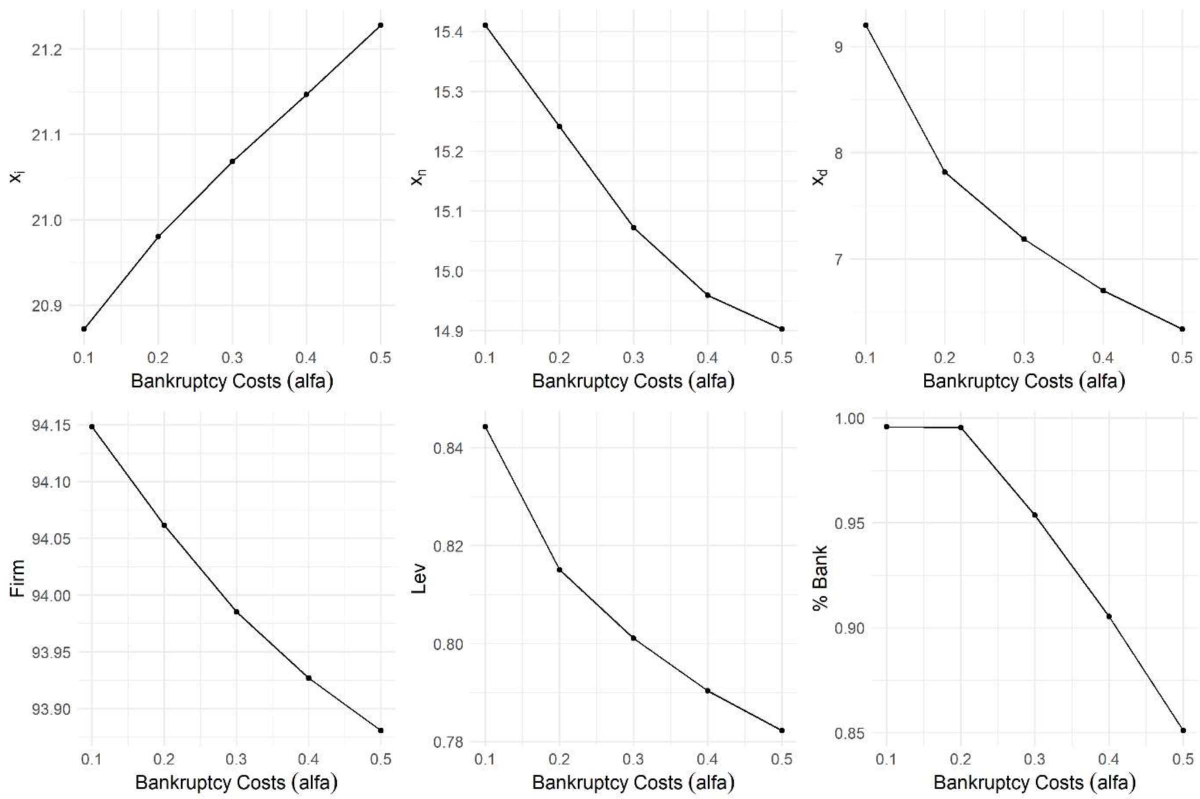
Notes: $x = 10, r = 0.05, \tau = 0.2, \mu = 0.01, \lambda = 0.05, \sigma = 0.15, \alpha = 0.5, ex = 1.1., I = 100, \eta = 1, q = 0 - 0.5$. Reduction in ESG risk $k = 0.025$. Firm refers to equity value at t = 0.

Figure A3. The effect of debt holders bargaining power (η).



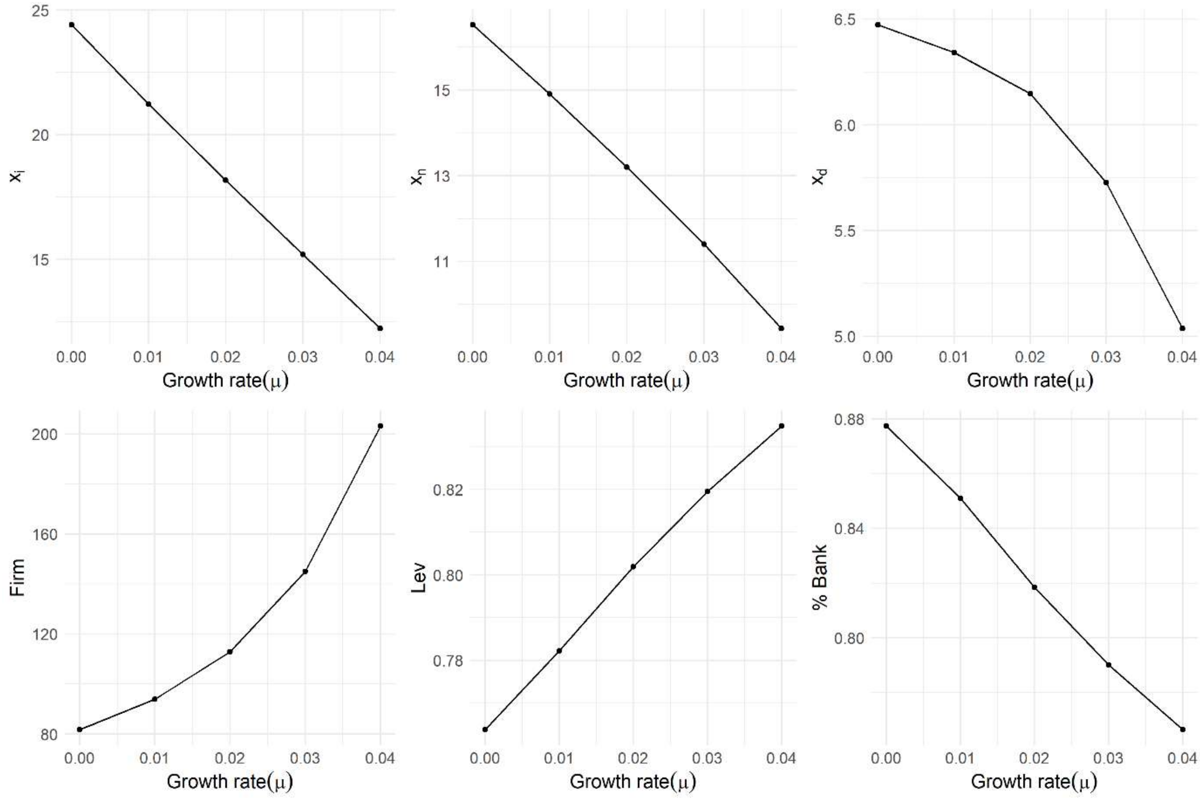
Notes: $x = 10, r = 0.05, \tau = 0.2, \mu = 0.01, \lambda = 0.05, \sigma = 0.15, \alpha = 0.5, ex = 1.1., I = 100, \eta = 1 - 1.4, q = 0$. Reduction in ESG risk $k = 0.025$. Firm refers to equity value at t = 0. The dotted blue lines indicate that values are constant and is a result of minor oscillations in numerical approximations.

Figure A4. The effect of bankruptcy costs (α)



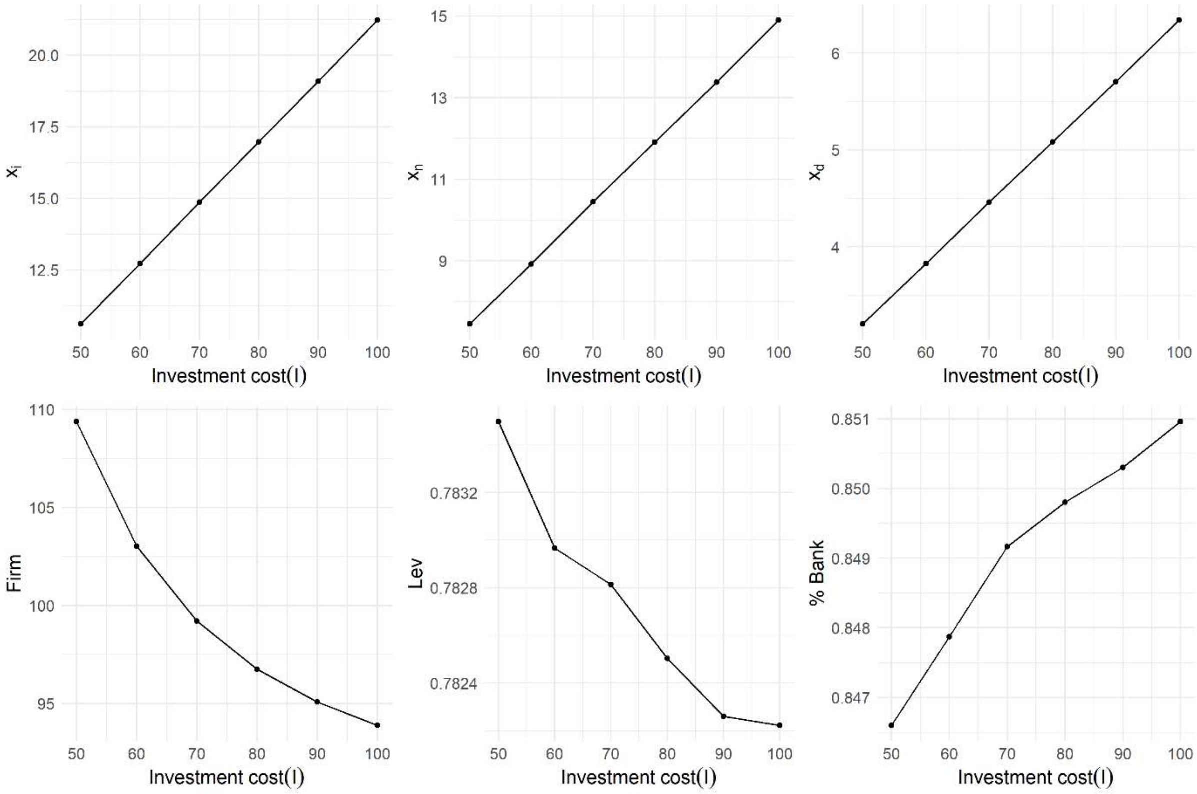
Notes: $x = 10, r = 0.05, \tau = 0.2, \mu = 0.01, \lambda = 0.05, \sigma = 0.15, \alpha = 0.1 - 0.5, ex = 1.1., I = 100, \eta = 1, q = 0$. Reduction in ESG risk $k = 0.025$. Firm refers to equity value at t = 0.

Figure A5. The effect of growth rate (μ).



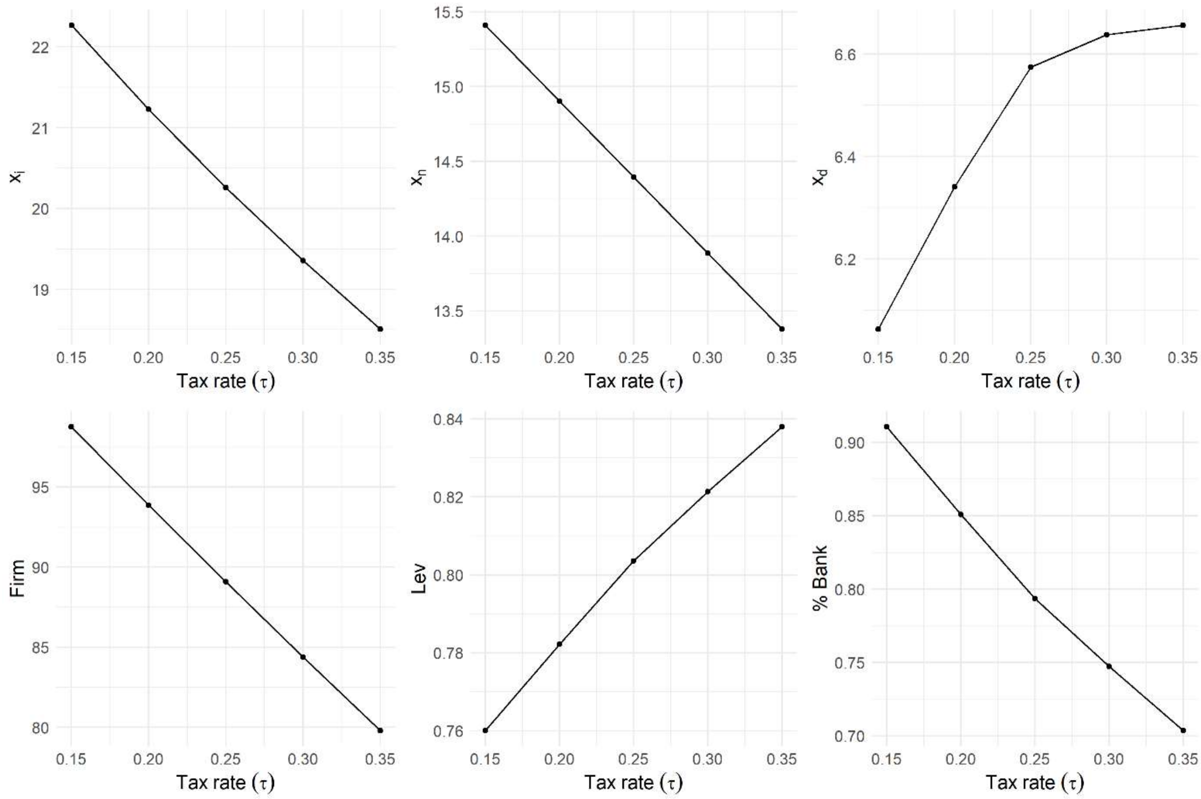
Notes: $x = 10, r = 0.05, \tau = 0.2, \mu = 0 - 0.04, \lambda = 0.05, \sigma = 0.15, \alpha = 0.5, ex = 1.1., I = 100, \eta = 1, q = 0$. Reduction in ESG risk $k = 0.025$. Firm refers to equity value at t = 0.

Figure A6. The effect of investment cost (I).



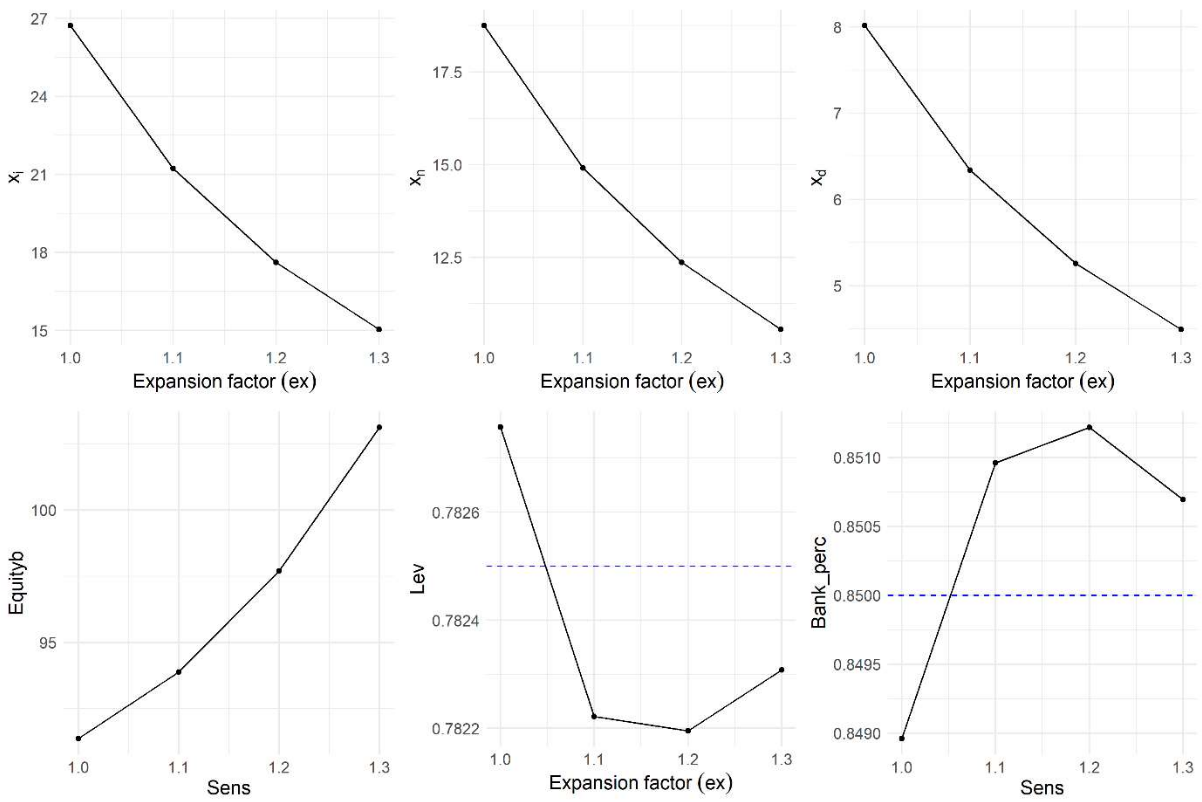
Notes: $x = 10, r = 0.05, \tau = 0.2, \mu = 0.01, \lambda = 0.05, \sigma = 0.15, \alpha = 0.5, ex = 1.1., I = 50 - 100, \eta = 1, q = 0$. Reduction in ESG risk $k = 0.025$. Firm refers to equity value at t = 0.

Figure A7. The effect of tax rate (τ)



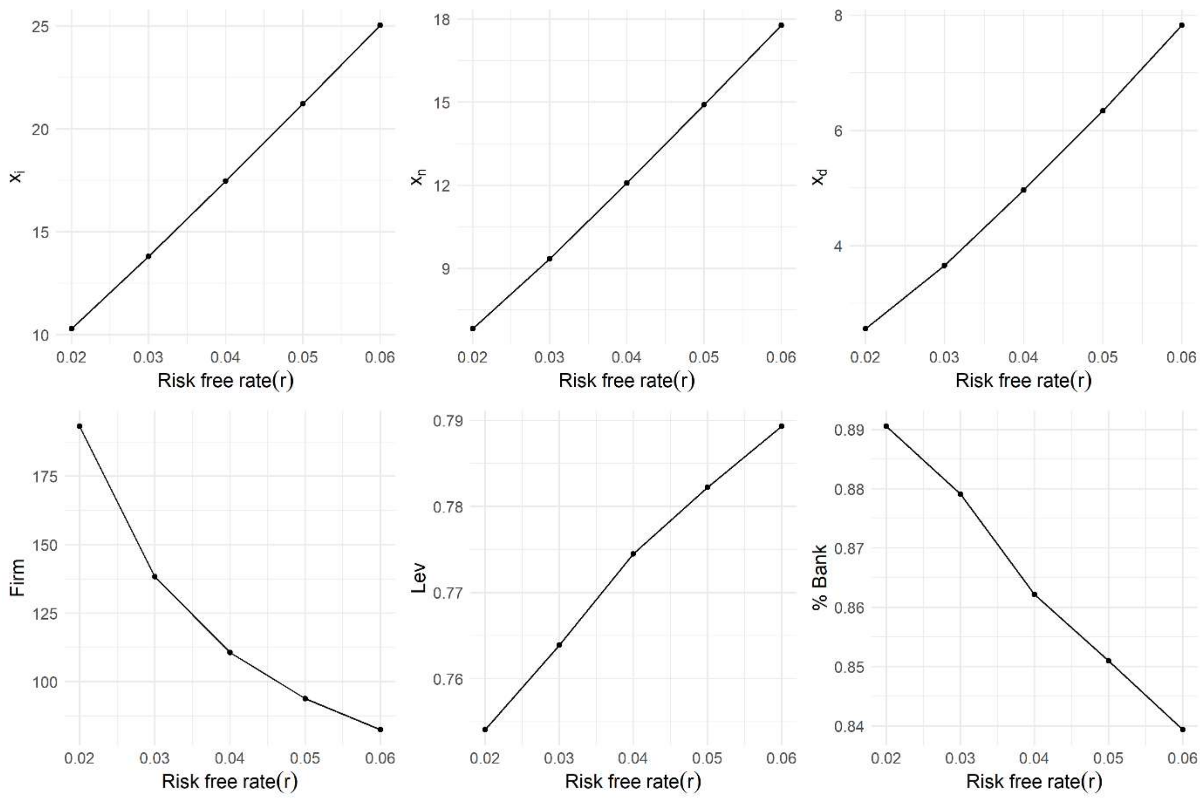
Notes: $x = 10, r = 0.05, \tau = 0.15 - 0.35, \mu = 0.01, \lambda = 0.05, \sigma = 0.15, \alpha = 0.5, ex = 1.1., I = 100, \eta = 1, q = 0$. Reduction in ESG risk $k = 0.025$. Firm refers to equity value at t = 0.

Figure A8. The effect of expansion factor (ex)



Notes: $x = 10, r = 0.05, \tau = 0.2, \mu = 0.01, \lambda = 0.05, \sigma = 0.15, \alpha = 0.5, ex = 1 - 1.6., I = 100, \eta = 1, q = 0$. Reduction in ESG risk $k = 0.025$. Firm refers to equity value at t = 0. The dotted blue lines indicate that values are constant and is a result of minor oscillations in numerical approximations.

Figure A9. The effect of risk-free rate (r)



Notes: $x = 10, r = 0.02 - 0.05, \tau = 0.2, \mu = 0.01, \lambda = 0.05, \sigma = 0.15, \alpha = 0.5, ex = 1.1, I = 100, \eta = 1, q = 0$. Reduction in ESG risk $k = 0.025$. Firm refers to equity value at t = 0.