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Corporate sustainability, investment, and capital structure

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Abstract

This study develops a real options model in which a firm invests in either a sustainable project or an unsustainable project. The sustainable project requires a high investment cost and yields cash flows perpetually, whereas the unsustainable project requires a low investment cost and yields cash flows until a random maturity. The random termination of cash flows reflects the project's environmental, social, and governance (ESG) risk. In the model, the optimal investment choice and timing are analytically derived, and the effects of key parameters on the choice are also examined. Higher ESG risk, growth rate, and volatility, and lower discount rate encourage sustainable investing mainly through their impacts on the net present value (NPV) and timing option value. The less sustainable firm chooses higher leverage to enjoy a greater benefit of debt financing. Therefore, access to debt financing and a higher corporate tax rate (tax shield) discourage sustainable investing.

JEL Classifications Code: G13; G31; G32.

Keywords: sustainability; ESG; real options; capital structure.

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1 Introduction

Over the last decade, firms have identified the importance of the sustainability of their operations in capital budgeting decisions. International organizations and governments have also become more active in resolving sustainability issues (e.g., the 17 sustainable development goals by the United Nations). In these circumstances, an increasing number of academic researchers have also investigated a variety of aspects of sustainability issues. For instance, several studies have applied operations research methodologies, such as multi-criteria decision-making methods, to the assessment of sustainability (for a survey, see Thies, Kieckhafer, Spengler, and Sodhi (2019)). In the finance area, many papers have investigated ESG investment (e.g., Hong and Kacperczyk (2009), Bolton and Kacperczyk (2021), and Pedersen, Fitzgibbons, and Pomorski (2021)). Many presentations at the 32nd European Conference on Operational Research also discussed the effectiveness of ESG investment (e.g., Grassetti and Stocco (2022), D'Ecclesia, Stefanelli, and Morelli (2022), Nicolosi, Cerqueti, Ciciretti, and Dalo (2022), and Castellano (2022)).[1] Most of the existing literature addresses the relationships among ESG performance, firm characteristics, firm risk, and firm value (for a survey, see Gillan, Koch, and Starks (2021)).

Despite the growing body of research, few papers have attempted to address sustainability issues in the framework of the capital budgeting decision theory. To this point, no theory has explained the economic mechanisms of market, firm, and institutional characteristics' effects on corporate investing in sustainable projects. This paper aims to fill that research gap and apply the real options modeling approach to reveal the conditions that stimulate corporate investing in sustainable projects.[2]

For this purpose, the present study uses the following model. Consider a firm that has an option to invest in one of two projects (i.e., sustainable and unsustainable projects). There is a tradeoff between ESG risk and investment cost. The sustainable project requires a high investment cost and yields cash flows perpetually, while the unsustainable project requires a low investment cost and yields cash flows until a random maturity, which follows a Poisson arrival process and reflects the project's ESG risk. After evaluating the tradeoff, the firm optimizes its investment choice and timing to maximize financial value.[3] In addition to investigating an unlevered model, this paper examines a levered model in which the firm also optimizes debt issuance (i.e., capital structure) at the time of investment.

[1] More than fifty presentations at the 32nd European Conference on Operational Research were related to sustainability issues (not limited to ESG investment) according to the program.

[2] The model is based on real options theory (e.g., Dixit and Pindyck (1994)). The real options method is now widely accepted as a better method than the NPV method specifically in capital budgeting decisions involving uncertainty and irreversibility (for a review, see Kozlova (2017) and Trigeorgis and Tsekrekos (2018)).

[3] This paper focuses on an ESG-aware firm that recognizes ESG risk and maximizes financial value. On the other hand, some papers consider that firms or investors take nonfinancial benefits from sustainable projects into account (e.g., Pedersen, Fitzgibbons, and Pomorski (2021) and Oehmke and Opp (2022)). Such firms are regarded as ESG-motivated firms. The differences are explained in Section 2.3.

Certain practical examples can validate the model. Imagine a hypothetical mining firm that plans to exploit natural resources (say, gold). Generally, mining activities cause many environmental problems, but it is possible to mitigate environmental damage at a cost. In this case, the firm chooses one of the two means of exploitation (i.e., traditional exploitation with environmental damage or costly but eco-friendly exploitation), with the knowledge that environmentally destructive mining might be prohibited in the future. The firm makes its investment choice and timing decisions by observing the international market price of gold, which determines the project's cash flows. Another example is an apparel firm that plans to invest in a factory in a developing country. The firm chooses one of two factory types (i.e., a factory with or without sufficient labor rights), and learns that the labor-exploiting factory has a risk of disaster and closure as a reaction to public criticism (e.g., the Dhaka garment factory fire in Bangladesh). The firm makes its investment choice and timing decisions based on the ESG risk and market demand for its apparel products.

This paper analytically solves the model and derives the explicit condition (hereafter, the sustainability condition) under which the firm chooses the sustainable project. The effects of key parameters on the sustainability condition are also examined analytically and numerically. These parameters can impact the firm's investment choice through three channels: (i) the NPV of project cash flows, (ii) the value of the option to defer investment, and (iii) optimal capital structure. Higher ESG risk, unsustainable investment cost, and lower sustainable investment cost lead the firm to invest in the sustainable project through the NPV channel. Lower discount rate and higher cash flow growth rate increase the value of cash flows in the far future and, through the NPV and option channels, encourage sustainable investing. Higher cash flow volatility encourages sustainable investing through the option channel. In fact, higher volatility increases the option value of waiting for a better economic state and investing in the high-cost and high-profit project (i.e., the sustainable project) rather than in the low-cost and low-profit project (i.e., the unsustainable project).

Debt financing difficulties and a lower corporate tax rate do not have the NPV and option channels but nonetheless encourage sustainable investing through the capital structure channel. The unsustainable project increases its value by debt financing more than the sustainable project because the unsustainable firm cares less about bankruptcy costs, increases leverage, and enjoys the higher leverage multiplier effect. Consequently, difficulty in debt financing and a lower corporate tax rate suppress debt financing and lead the firm to invest in the sustainable project, although this capital structure channel is relatively weak.

These results have significant implications for sustainability issues. Not only cost structures (e.g., technological innovations and subsidies) and degree of ESG risk (e.g., regulations and publicity), but also market conditions (e.g., discount rate, growth rate, and volatility) and the government policies (e.g., interest rate and tax rate) affect corporate decisions to invest in sustainable projects. Typically, large and listed firms in developed countries are active in resolving sustainability issues. This trend can be rationally explained by these firms' and countries' characteristics of lower discount rate and higher ESG risk (or publicity). That is, these firms have a greater economic rationale to invest sustainably than small and unlisted firms in developing countries do.

So far, I have focused on the choice between sustainable and unsustainable projects, but in terms of investment timing, sustainable project investment timing is later (due to its high investment cost) than unsustainable project investment timing is. By consequence, parameter changes (e.g., market and policy changes) that promote sustainable investing do not necessarily accelerate corporate investment. Although parameter changes could lead firms to invest in more sustainable projects, they delay investment timing. Thus, the effects of parameters on investment timing become non-monotonic.

Last, I will explain technically related literature. In the real options modeling literature on sustainability issues, many papers have studied investment timing and valuation of renewable energy projects (for a review, see Kozlova (2017)). For instance, Boomsma, Meade, and Fleten (2012) analyze investment timing and capacity decisions on renewable energy projects under two support schemes and reveal those support schemes' differing impacts on the decisions. As in this paper's use of a Poisson jump to model ESG risk, Boomsma and Linnerud (2015) and Adkins and Paxson (2016) model renewable policy uncertainty using Poisson jumps and show the effects of the policy uncertainty on renewable investment timing and valuation. However, these previous studies do not examine the process of making a decision between sustainable and unsustainable projects that accounts for the tradeoff between ESG risk and investment cost, nor do their models incorporate debt financing. Therefore, unlike this paper, they do not clarify the conditions that promote sustainable investment and those conditions' relation to capital structure.

Apart from sustainability issues, many papers examine real options models of investment and debt financing. Seminal studies by Mauer and Sarkar (2005), Sundaresan and Wang (2007), and Sundaresan, Wang, and Yang (2015) show the effects of debt financing on investment timing, agency cost, and firm value by integrating McDonald and Siegel (1986)'s investment timing model with Leland (1994)'s capital structure model. In this context, Shibata and Nishihara (2012) and Shibata and Nishihara (2018) show the effects of debt borrowing constraints on investment timing, capital structure, and firm value. However, these previous studies do not consider the process of selecting one project from among several alternatives. By incorporating the choice between sustainable and unsustainable projects in their levered setup, this paper unveils the relationships of between corporate sustainability and capital structure.

The remainder of this paper is organized as follows. Section 2 introduces the model setup. Section 3 shows the solutions in the unlevered and levered models. In particular, the sustainability conditions are explicitly derived in both models. Section 4 numerically explores the effects of the key parameters on investment choice, timing, and capital structure. Section 5 concludes the paper.

2 Model setup

2.1 Unlevered model

Consider a firm that has an option to invest in either an unsustainable project by paying investment cost I_1 or a sustainable project by paying investment cost I_2, where $0 < I_1 < I_2$ holds. Throughout the paper, subscripts 1 and 2 stand for the unsustainable and sustainable projects. The firm must choose only one of the available projects for reasons such as operational and financial constraints. After investing in either project, the firm receives continuous streams of earnings before interest and taxes (EBIT) $X(t)$, which follows a geometric Brownian motion

$$\mathrm{d}X(t) = \mu X(t)\mathrm{d}t + \sigma X(t)\mathrm{d}B(t) \ (t > 0), \quad X(0) = x,$$

where $B(t)$ denotes the standard Brownian motion defined in a filtered probability space $(\Omega, \mathcal{F}, \mathbb{P}, \{\mathcal{F}_t\})$ and $\mu, \sigma(> 0)$ and $x(> 0)$ are constants. Apply the corporate tax rate $\tau \in (0, 1)$ to $X(t)$. EBIT $X(t)$ lasts perpetually for the sustainable project, but for the unsustainable project, $X(t)$ matures at a random time, which follows an exponential distribution with rate $\lambda(> 0)$. The maturity means the time of the firm' exit from the market. For simplicity, the model assumes the independence between $X(t)$ and the exponential distribution.

Parameter λ stands for ESG risk of the unsustainable project. For instance, high-pollution technologies and products made with exploited labor could be legally banned on the grounds of ESG concerns. Even if such projects are not legally banned, ESG concerns could nonetheless force them to exit the market by attracting significant attention in the era of social networks.[4] To reduce the risks of such future penalties, firms would have to pay higher costs (e.g., by implementing low-pollution technologies and making products with expensive labor). To capture this situation as simply as possible, the model assumes the unsustainable project to have ESG risk λ and low investment cost I_1 and the sustainable project to have no ESG risk and high investment cost I_2. By assessing the tradeoff of ESG risk and investment cost, the firm optimizes investment choice and timing.[5]

[4]For simplicity, the model assumes that ESG risk will arise only after the unsustainable project initiation. This means that the firm's poor ESG activity attracts public attention and causes regulatory measures or backlash. In some situations, unsustainable investment options may also entail ESG risk even before investment. In fact, the first draft of this paper studied such a model. In this case, the firm acts as if it faces alternative investment opportunities with different discount rates. Then, the choice is dynamically inconsistent, and there is no explicit sustainability condition like (3) and (24). I computed the firm's policy and value under the assumption that the firm chooses a higher-valued project at time 0 and found that the results are qualitatively the same as those of this paper.

[5]In practice, the lifetime of sustainable projects may be finite, but it is expected to be longer than that of unsustainable projects. Firms may have options to invest in (i.e., switch to) sustainable projects after unsustainable projects are forced to terminate. However, the remaining option values will be lower than the values of firms that choose sustainable projects from the beginning, due to switching costs, reputational damage, and competitors' preemption, etc. Although the difference between the sustainable and unsustainable projects (i.e., the impacts of ESG risk λ) is smaller in these detailed setups, this paper's main results will remain qualitatively unchanged.

The assumption of the unsustainable project's characteristics is based on empirical evidence that firms with poor ESG practices have high credit, legal, and downside risks (see Table 4 in Gillan, Koch, and Starks (2021)). For instance, Jagannathan, Ravikumar, and Sammon (2018) show that ESG risks are identified as rare, large, and nondiversifiable downside risks, and Seltzer, Starks, and Zhu (2022) show that firms with poor environmental performance have high credit risk particularly in states with stringent environmental regulations. On the other hand, there have been mixed empirical findings about the effects of ESG performance on firm (project) value (see Table 5 in Gillan, Koch, and Starks (2021)). Based on the ambiguous findings, the model assumes the same cash flow process for both projects. This simplifying assumption renders the model one-dimensional and facilitates an analytical solution.

2.2 Levered model

As in the standard models of dynamic investment and financing based on tradeoff theory (e.g., Shibata and Nishihara (2012) and Sundaresan, Wang, and Yang (2015)), the firm issues consol debt at investment time. The firm optimizes debt level (i.e., the coupon of debt) in addition to investment choice and timing. With debt, shareholders are better off declaring default than continuing operation and coupon payments when EBIT $X(t)$ falls to a certain threshold. In bankruptcy, shareholders receive nothing, and debt holders takes over the unlevered firm value,[6] where a fraction $\alpha \in (0,1)$ of the firm value is lost to the deadweight costs of bankruptcy (e.g., filing and attorney fees). If the firm invests in the unsustainable project, the firm could potentially exit from the market before default.

2.3 Firm types

In the baseline model, the firm is fully aware of ESG risk and optimizes its investment and financing policy to maximize financial value. That is, the firm can choose either a sustainable project or an unsustainable project by taking into account the tradeoff between ESG risk and investment cost.

For comparison, this paper considers ESG-unaware and ESG-motivated firms. The ESG-unaware firm mistakenly assumes no ESG risk, i.e., $\lambda = 0$. The ESG-unaware firm optimizes its investment and financing policy to maximize financial value under the faulty assumption. Because of the assumption $\lambda = 0$, the ESG-unaware firm prefers the unsustainable project with lower investment costs I_1. By contract, the ESG-motivated firm gains extra value $\Delta I = I_2 - I_1$ in addition to financial value gained by investing in the sustainable project. The extra value can be interpreted as nonfinancial benefits or utility from the improvement of ESG performance (cf. Pedersen, Fitzgibbons, and Pomorski (2021)). The ESG-motivated firm prefers the sustainable project because the extra value ΔI fully compensates for the project's high investment cost I_2. For simplicity, this paper assumes that equity and debt holders have the same information and preferences

[6]This paper does not distinguish between liquidation and reorganization bankruptcy. The unlevered value can be interpreted as the liquidation or operating-concern value.

about ESG risk. It could be an interesting issue for future study to investigate the agency conflicts on ESG risk by incorporating asymmetric information and preferences between equity and debt holders.

This paper's classification of firms into one of three categories (i.e., the ESG-aware, ESG-unaware, and ESG-motivated firms) is based on those introduced by Pedersen, Fitzgibbons, and Pomorski (2021). I focus on the ESG-aware firm as the baseline case for the following two reasons. First, the ESG-aware firm's problem is the most complicated and interesting because it addresses the tradeoff between ESG risk and investment cost. In fact, because the other two types of firm face no such tradeoff, their choice of project is clear-cut. Second, several studies (e.g., Bellon (2020) and Cai, Zhu, Zhang, Li, and Xie (2020)) indicate that ESG-aware firms seem prevalent in reality.

3 Model solutions

3.1 Unlevered model solutions

The expected NPV of cash flows starting from $X(0) = x$ at time 0 is calculated as

$$\mathbb{E}[\int_0^\infty \lambda \mathrm{e}^{-\lambda s} \int_0^s \mathrm{e}^{-rt}(1-\tau)X(t)\mathrm{d}t\mathrm{d}s] = a_1^U x \tag{1}$$

for the unsustainable project and

$$\mathbb{E}[\int_0^\infty \mathrm{e}^{-rt}(1-\tau)X(t)\mathrm{d}t] = a_2^U x$$

for the sustainable project, where $a_1^U = (1-\tau)/(r-\mu+\lambda)$ and $a_2^U = (1-\tau)/(r-\mu)$. Throughout the paper, superscript U represents the unlevered model. Multiplier a_1^U is lower than a_2^U because of random termination of cash flows. By the strong Markov property of $X(t)$, the expected NPV of cash flows starting from $X(t) = t$ at time t becomes $a_1^U X(t)$ for the unsustainable project and $a_2^U X(t)$ for the sustainable project. The unlevered firm (option) value at time 0 is expressed as

$$V^U(x) = \sup_{T\in\mathcal{T}} \mathbb{E}[\mathrm{e}^{-rT} \max_{i=1,2}\{a_i^U X(T) - I_i\}], \tag{2}$$

where $\mathcal{T}$ denotes the set of $\mathcal{F}_t$-stopping times. That is, the firm chooses its investment time T and a higher-valued project using information available until time T.

Optimal stopping problem (2) is technically the same as the one solved by Décamps, Mariotti, and Villeneuve (2006). By using their results (see also Nishihara and Ohyama (2008)), I can show the following proposition, where $\beta = 0.5 - \mu/\sigma^2 + \sqrt{(\mu/\sigma^2 - 0.5)^2 + 2r/\sigma^2}(> 1)$ is the positive characteristic root. For the proof, see Appendix A.

Proposition 1 *If sustainability condition*

$$\left(\frac{r-\mu+\lambda}{r-\mu}\right)^{\frac{\beta}{\beta-1}} \geq \frac{I_2}{I_1}, \tag{3}$$

holds, the firm chooses the sustainable project. The value function and investment threshold are given by

$$V^U(x) = \begin{cases} (a_2^U x_2^U - I_2)\left(\dfrac{x}{x_2^U}\right)^\beta & (x < x_2^U) \\ a_2^U x - I_2 & (x \geq x_2^U), \end{cases} \tag{4}$$

and

$$x_2^U = \frac{\beta I_2}{(\beta - 1)a_2^U}. \tag{5}$$

Otherwise, the firm chooses either a sustainable project or an unsustainable project. The value function and investment threshold are given by

$$V^U(x) = \begin{cases} (a_1^U x_{11}^U - I_1)\left(\dfrac{x}{x_{11}^U}\right)^\beta & (x < x_{11}^U) \\ a_1^U x - I_1 & (x \in [x_{11}^U, x_{12}^U]) \\ (a_1^U x_{12}^U - I_1)\Delta^U(x) + (a_2^U x_{21}^U - I_2)\Sigma^U(x) & (x \in (x_{12}^U, x_{21}^U)) \\ a_2^U x - I_2 & (x \geq x_{21}^U), \end{cases} \tag{6}$$

where $\Delta^U(x)$ and $\Sigma^U(x)$ denote the state prices for $X(t)$ first reaching x_{12}^U from above and x_{21}^U from below, respectively (for the details, see (29) and (30) in Appendix A), and

$$x_{11}^U = \frac{\beta I_1}{(\beta - 1)a_1^U}, \tag{7}$$

where x_{12}^U and x_{21}^U are determined by the smooth pasting conditions (31) and (32) in Appendix A.

Remark 1 *The ESG-unaware firm invests in the unsustainable project at threshold*

$$x_3^U = \frac{\beta I_1}{(\beta - 1)a_2^U}, \tag{8}$$

whereas the ESG-motivated firm invests in the sustainable project at threshold x_3^U. Inequalities $x_3^U < x_2^U$ and $x_3^U < x_{11}^U$ hold, which means that the ESG-unaware and ESG-motivated firms invest earlier than the ESG-aware firm does. Because of the suboptimality of x_3^U, the financial values of the ESG-unaware and ESG-motivated firms are lower than that of the ESG-aware firm.

Sustainability condition (3) is equivalent to the condition that value function (4) dominates the payoff of the unsustainable project $a_1^U x - I_1$ for all $x \geq 0$. That is, under sustainability condition (3), the firm has no reason to invest in the unsustainable project for any $X(t)$. Value function (4) and investment threshold (5) are equal to those of the case in which only the sustainable project is available. In other words, under sustainability condition (3), the unsustainable project does not affect the firm at all.

If sustainability condition (3) does not hold, the solution is more complicated. The firm's project choice depends on the initial state variable $X(0) = x$. For $x < x_{11}^U$, the firm waits for the unsustainable investment, for $x \in [x_{11}^U, x_{12}^U]$, the firm immediately invests in the unsustainable project, and for $x \geq x_{21}^U$, the firm immediately invests in the sustainable project. A notable region is (x_{12}^U, x_{21}^U), where the firm waits to invest. The firm will undertake either an unsustainable project when $X(t)$ falls to x_{11}^U or a sustainable project when $X(t)$ increases to x_{12}^U. That is, for

$x \in (x_{12}^U, x_{21}^U)$, the firm postpones its project choice. Then, the value function includes the state prices for the unsustainable and sustainable investments. The first term represents the value of the option of investing in the unsustainable project, while the second term represents the value of the option of investing in the unsustainable project. An interesting insight from this area is that a decrease in EBIT can trigger the unsustainable investment, while an increase in EBIT can trigger the sustainable investment.

Although the intermediate region (x_{12}^U, x_{21}^U) is interesting, most of the real options literature assumes that the initial state variable is low enough to exclude immediate investment. Following this standard, Section 4 will assume baseline parameter values satisfying $x < x_{11}^U$ and $x < x_2^U$. In this case, the firm chooses the unsustainable project if sustainability condition (3) is not satisfied. Thus, sustainability condition (3) determines whether the firm chooses the sustainable project. The next proposition shows the comparative statics of sustainability condition (3) and helps answer the following questions: What institutional and market environments encourage sustainable investing? What types of firms are more eager to invest in sustainable projects? For the proof, see Appendix B.

Proposition 2 *Sustainability condition (3) is more likely to hold for higher I_1, λ, σ, and μ, as well as for lower I_2 and r.*

Obviously, higher I_1, λ, and lower I_2 increase the advantage of the sustainable NPV over the unsustainable NPV (i.e., a_2^U/a_1^U). Higher volatility σ increases the option value of postponing investment, and through the option effect, it increases the advantage of the high-cost and high-profit project (i.e., the sustainable project) over the low-cost and low-profit project (i.e., the unsustainable project). The impact of σ coincides with those of Décamps, Mariotti, and Villeneuve (2006) and Nishihara and Ohyama (2008). Higher growth rate μ and lower discount rate r increase the advantage of the sustainable project through the NPV and option effects. With higher μ and lower r, EBIT will remain at a significant level for a longer time, and hence, the advantage of the sustainable NPV over the unsustainable NPV (i.e., a_2^U/a_1^U) increases. Thus, the firm tends to avoid short-termism (i.e., the unsustainable project). Higher μ and lower r, like higher σ, also increase the option value of postponing investment and hence increase the advantage of the sustainable project.

Proposition 2 generates many insights. First, firm characteristics can affect a firm's choice between the alternative projects. For example, large and listed firms are more likely to face the institutional and social pressures of ESG concerns, which implies higher λ than that of small and private firms. Large and listed firms also tend to be more diversified, less financially constrained, and less operationally constrained; hence they use lower discount rates than small and private firms do (e.g., Harrington (1989), Krugger, Landier, and Thesmar (2015), Jagannathan, Matsa, Meier, and Tarhan (2016), Décaire (2020), and Nishihara (2021)). Because of higher λ and lower r, large and listed firms are more likely to choose sustainable projects than small and private firms are. In terms of economic rationality, this result explains observed trends that large and listed firms are more engaged in sustainability.

Proposition 2 also entails policy implications. What governmental policies will encourage sustainable investing? Of course, subsidies for sustainable projects decrease I_2, and penalties for unsustainable projects increase I_1. The government's proactive stances on regulations and information disclosures regarding ESG risks cause firms to perceive higher λ. These policies are frequently implemented to promote sustainability in the real world. Notably, Proposition 2 also suggests that monetary policies, such as decreasing interest rates and quantitative easing, encourage sustainable investments by decreasing r. I believe that one of the reasons that firms have paid great attention to sustainability over the last decade lies in the historically low interest rates that followed the Great Recession.

From an international perspective, developed countries frequently blame developing countries for poor ESG practices when there are externalities (e.g., climate change caused by greenhouse gas emissions). However, interest rates vary among countries and tend to be higher in developing countries. All else being equal, developing countries with higher interest rates valuate unsustainable projects higher (i.e., short-termism) than developed countries do. To maintain the levels of ESG practices established by developed countries, developing countries have to take more proactive ESG policies (i.e., subsidies, penalties, and regulations) than developed countries do. In other words, the promotion of sustainability is more costly in developing countries than it is in developed countries, which causes conflict between developed and developing countries over ESG issues.

3.2 Levered model solution

3.2.1 Default decisions

The problem is solved backward. First, consider the unsustainable firm that issued debt with coupon C at time 0. Following the standard literature (e.g., Leland (1994) and Goldstein, Ju, and Leland (2001)), shareholders do not take into account debt in place and optimize default time T^D for their own interests. The equity value of the firm is the solution to the optimal stopping problem

$$\begin{aligned}
E_1(x;C) &= \sup_{T^D\in\mathcal{T}} \mathbb{E}[\int_0^\infty \lambda \mathrm{e}^{-\lambda s}\int_0^{\min\{s,T^D\}} \mathrm{e}^{-rt}(X(t)-C)\mathrm{d}t\mathrm{d}s] \qquad (9)\\
&= \mathbb{E}[\int_0^\infty \lambda \mathrm{e}^{-\lambda s}\int_0^{s} \mathrm{e}^{-rt}(X(t)-C)\mathrm{d}t\mathrm{d}s] + \sup_{T^D\in\mathcal{T}} \mathbb{E}[\int_{T^D}^\infty \lambda \mathrm{e}^{-\lambda s}\int_{T^D}^{s} \mathrm{e}^{-rt}(C-X(t))\mathrm{d}t\mathrm{d}s]\\
&= a_1^U x - \frac{(1-\tau)C}{r+\lambda} + \sup_{T^D\in\mathcal{T}} \mathbb{E}[\mathrm{e}^{-(r+\lambda)T^D}\left(\frac{(1-\tau)C}{r+\lambda} - a_1^U X(T^D)\right)] \qquad (10)\\
&= a_1^U x - \frac{(1-\tau)C}{r+\lambda} + \left(\frac{x}{x_1^D(C)}\right)^{\gamma_1}\left(\frac{(1-\tau)C}{r+\lambda} - a_1^U x_1^D(C)\right), \qquad (11)
\end{aligned}$$

where the strong Markov property of $X(t)$ is used in (10), γ_1 denotes the negative characteristic root

$$\gamma_1 = 0.5 - \frac{\mu}{\sigma^2} - \sqrt{\left(\frac{\mu}{\sigma^2}-0.5\right)^2 + \frac{2(r+\lambda)}{\sigma^2}}(<0), \qquad (12)$$

and default threshold $x_1^D(C)$ is derived as

$$x_1^D(C) = \frac{\gamma_1}{\gamma_1 - 1}\frac{(r-\mu+\lambda)C}{r+\lambda}. \qquad (13)$$

More intuitively, one can also derive equity value (11) and default threshold (13) as the solution to differential equation

$$\mu x \frac{\partial E_1(x;C)}{\partial x} + 0.5\sigma^2 x^2 \frac{\partial^2 E_1(x;C)}{\partial^2 x} + \lambda(-E_1(x;C)) + x - C = rE_1(x;C) \tag{14}$$

with the value matching condition $E_1(x^D(C);C) = 0$ and smooth pasting condition $\partial E_1(x^D(C);C)/\partial x = 0$, and boundary condition $\lim_{x\to\infty} E_1(x;C)/x < \infty$ (cf. Chapter 5.5.B of Dixit and Pindyck (1994)).[7] Note that in (14), term $\lambda(-E_1(x;C))$ represents that $E_1(x;C)$ becomes 0 at probability $\lambda \mathrm{d}t$ in infinitesimal time interval $\mathrm{d}t$. The solution to (14) is exactly the same as (11) and (13). Similarly, the debt and firm values are derived as follows:

$$D_1(x;C) = \frac{C}{r+\lambda} - \left(\frac{x}{x_1^D(C)}\right)^{\gamma_1} \left(\frac{C}{r+\lambda} - (1-\alpha)a_1^U x_1^D(C)\right), \tag{15}$$

$$F_1(x;C) = a_1^U x + \frac{\tau C}{r+\lambda} - \left(\frac{x}{x_1^D(C)}\right)^{\gamma_1} \left(\frac{\tau C}{r+\lambda} + \alpha a_1^U x_1^D(C)\right). \tag{16}$$

The equity, debt, and firm values (11), (15), and (16) resemble the standard valuations without random maturity (e.g., Leland (1994), Goldstein, Ju, and Leland (2001), Shibata and Nishihara (2012), and Sundaresan, Wang, and Yang (2015)). Indeed, (11), (15), and (16) are equal to the standard valuations with discount rate $r+\lambda$. That is, as in Chapter 6.4.A of Dixit and Pindyck (1994), one can regard the firm as infinitely lived but augment the discount rate by adding the termination probability parameter λ. As in the standard literature, equations (11), (15), and (16) can be interpreted as follows. The first two terms in (11) are the equity value of operating the firm with no default, while the last term represents the value of the default option. Debt value (15) is equal to the value of receiving coupons with no bankruptcy minus the loss associated with bankruptcy. Firm value (16) is composed of the unlevered firm value, tax benefits of debt, and bankruptcy costs.c

Now, consider optimal capital structure. As described in the standard literature (e.g., Leland (1994) and Goldstein, Ju, and Leland (2001)), the firm chooses coupon C to maximize the firm value $F_1(x;C)$ (which is equal to the ex-ante equity value). By the first-order condition $\partial F_1(x;C)/\partial C = 0$, the optimal coupon is derived as

$$C_1(x) = \frac{r+\lambda}{r-\mu+\lambda} \frac{\gamma_1 - 1}{\gamma_1} \frac{x}{h_1}. \tag{17}$$

By (13), (16), and (17), the optimal firm value is derived as

$$F_1(x;C_1(x)) = \phi_1 a_1^U x, \tag{18}$$

where h_1 and ϕ_1 are constants defined by

$$h_1 = \left[1 - \gamma_1\left(1 - \alpha + \frac{\alpha}{\tau}\right)\right]^{-\frac{1}{\gamma_1}} (> 1), \tag{19}$$

$$\phi_1 = 1 + \frac{\tau}{(1-\tau)h_1} (> 1). \tag{20}$$

[7] I present this solution method because this method may be more prevalent in the finance area.

The leverage and credit spreads are also derived explicitly as

$$LV_1 = \frac{D_1(x; C(x))}{F_1(x, C(x))} = \frac{\gamma_1 - 1}{\gamma_1} \frac{1 - \xi_1}{\phi_1 h_1 (1 - \tau)}, \tag{21}$$

$$CS_1 = \frac{C_1(x)}{D_1(x; C_1(x))} - r = \frac{r\xi_1 + \lambda}{1 - \xi_1}, \tag{22}$$

where ξ_1 is a constant defined by

$$\xi_1 = \frac{(1 - (1 - \alpha)(1 - \tau)\gamma_1)(h_1)^{\gamma_1}}{\gamma_1 - 1}.$$

These solutions are the same as those of the infinitely-lived firm with augmented discount rate $r + \lambda$ in previous studies (e.g., Nishihara and Shibata (2010), Shibata and Nishihara (2012), and Sundaresan, Wang, and Yang (2015)). The difference between the unlevered firm value (1) and levered firm value (18) is the multiplier $\phi_1 (> 1)$, which measures the effect of optimal leverage on firm value. That is, the firm obtains higher value by choosing the optimal capital structure based on the tradeoff between the tax benefits of debt and bankruptcy costs.

The equity, debt, firm values, coupon, leverage, and credit spreads of the sustainable firm are equal to the above values with $\lambda = 0$ and are also derived in existing literature (e.g., Nishihara and Shibata (2010), Shibata and Nishihara (2012), and Sundaresan, Wang, and Yang (2015)). Hence, I will omit the equations and let subscript 2 represent the corresponding value of the sustainable firm. For instance, $C_2(x)$ and ϕ_2 represent optimal coupon (17) and leverage effect (20) with $\lambda = 0$, respectively, for the sustainable firm.

3.2.2 Investment and financing decisions

Now, consider the investment and financing decisions. By the strong Markov property of $X(t)$, the expected NPV of cash flows starting from $X(t) = t$ at time t becomes $a_1^L X(t)$ for the unsustainable project and $a_2^L X(t)$ for the sustainable project, where $a_1^L = \phi_1 a_1^U$ and $a_2^L = \phi_2 a_2^U$. The firm (option) value at time 0 is expressed as

$$V^L(x) = \sup_{T \in \mathcal{T}} \mathbb{E}[\mathrm{e}^{-rT} \max_{i=1,2} \{a_i^L X(T) - I_i\}], \tag{23}$$

where the firm chooses its investment time T and a higher-valued and leveraged project. The differences between problems (2) and (23) are leverage multipliers ϕ_1 and ϕ_2. Optimal stopping problem (23) is technically the same as the one solved by Décamps, Mariotti, and Villeneuve (2006). The following proposition is shown in the same manner as in Proposition 1. For the proof, see Appendix C.

Proposition 3 *If sustainability condition*

$$\left(\frac{(r - \mu + \lambda)\phi_2}{(r - \mu)\phi_1} \right)^{\frac{\beta}{\beta - 1}} \geq \frac{I_2}{I_1}, \tag{24}$$

holds, the firm chooses the sustainable project. The value function and investment threshold are given by

$$V^L(x) = \begin{cases} (a_2^L x_2^L - I_2) \left(\dfrac{x}{x_2^L} \right)^{\beta} & (x < x_2^L) \\ a_2^L x - I_2 & (x \geq x_2^L), \end{cases} \tag{25}$$

and

$$x_2^L = \frac{\beta I_2}{(\beta-1)a_2^L} = x_2^U/\phi_2. \tag{26}$$

Otherwise, the firm chooses either a sustainable project or an unsustainable project. The value function and investment threshold are given by

$$V^L(x) = \begin{cases} (a_1^L x_{11}^L - I_1)\left(\dfrac{x}{x_{11}^L}\right)^{\beta} & (x < x_{11}^L) \\ a_1^L x - I_1 & (x \in [x_{11}^L, x_{12}^L]) \\ (a_1^L x_{12}^L - I_1)\Delta^L(x) + (a_2^L x_{21}^L - I_2)\Sigma^L(x) & (x \in (x_{12}^L, x_{21}^L)) \\ a_2^L x - I_2 & (x \geq x_{21}^L), \end{cases} \tag{27}$$

where $\Delta^L(x)$ and $\Sigma^L(x)$ denote the state prices for $X(t)$ first reaching x_{12}^L from above and x_{21}^L from below, respectively (for the details, see (33) and (34) in Appendix C), and

$$x_{11}^L = \frac{\beta I_1}{(\beta-1)a_1^L} = x_{11}^U/\phi_1, \tag{28}$$

where x_{12}^L and x_{21}^L are determined by the smooth pasting conditions (35) and (36) in Appendix C.

Remark 2 *The ESG-unaware and ESG-motivated firms invest in the unsustainable and sustainable projects, respectively at threshold $x_3^L = x_3^U/\phi_2$. Inequalities $x_3^L < x_2^L$ and $x_3^L < x_{11}^L$ hold, which means that the ESG-unaware and ESG-motivated firms invest earlier than the ESG-aware firm does. Because of the suboptimality of x_3^U, the financial values of the ESG-unaware and ESG-motivated firms are lower than that of the ESG-aware firm.*

Proposition 3 can be interpreted as in Proposition 1. Indeed, sustainability condition (24) is equivalent to the condition that value function (25) dominates the unsustainable project's payoff $a_1^L x - I_1$ for all $x \geq 0$. Value function (25) and investment threshold (26) are equal to those of the levered model in which only the sustainable project is available. If sustainability condition (24) does not hold, the firm's project choice depends on the initial state variable $X(0) = x$. The regions $x < x_{11}^L$ and $x \geq x_{21}^L$ are the unsustainable and sustainable investment regions, respectively, whereas the other two regions are the waiting regions. A notable region is (x_{12}^L, x_{21}^L), where the firm waits to invest until $X(t)$ reaches either low threshold x_{11}^L or high threshold x_{12}^L.

As explained after Proposition 1, Section 4 will assume a sufficiently small initial state variable $X(0) = x$ satisfying $x < x_{11}^L$ and $x < x_2^L$. Then, under sustainability condition (24), the firm will invest in the sustainable project and issue debt with coupon $C_2(x_2^L)$ at threshold x_2^L and go bankrupt at threshold $x_2^D(C_2(x_2^L)) = x_2^L/h_2$. If sustainability condition (24) does not hold, the firm will invest in the unsustainable project and issue debt with coupon $C_1(x_{11}^L)$ at threshold x_{11}^L and either go bankrupt at threshold $x_1^D(C_1(x_{11}^L)) = x_{11}^L/h_1$ or be forced to exit before bankruptcy.

Obviously, sustainability condition (24) is more likely to hold for higher I_1 and lower I_2. I cannot mathematically show the impacts of λ, σ, μ, and r on condition (24) because their impacts on the ratio of the leverage effect ϕ_2/ϕ_1 are complicated. However, Section 4 will show numerically that their impacts remain unchanged from Proposition 2. The main reason is that the impact through the leverage effect is indirect and weaker than the impacts through the NPV and option effects. The question remains as to whether access to debt financing encourages sustainable investing. Notably, the next proposition answers this question in the negative. For the proof, see Appendix D.

Proposition 4 *The leverage effect ϕ_1 increases in λ, which implies $\phi_1 > \phi_2$. Hence, sustainability condition (24) is less likely to hold than sustainability condition (3).*

The positive derivative $\partial\phi_1/\partial\lambda > 0$ means that the leverage effect is larger for the less sustainable firm. The tradeoff between the tax benefits of debt and bankruptcy costs explains this economic mechanism as follows. The unsustainable firm is forced to exit regardless of its debt level at a random maturity, and hence, bankruptcy costs are not relevant in the forced exit case. That is, bankruptcy costs matter only when the firm defaults earlier than the forced exit. Thus, with a less sustainable project (i.e., higher λ), the firm perceives lower bankruptcy costs, increases leverage LV_1, and enjoys larger leverage multiplier ϕ_1.[8] For instance, if the firm knows that it will be terminated in one year, it only needs to care about one year of operation. Accordingly, the unsustainable firm chooses higher leverage to increase its value compared to the sustainable firm, which cares about long-term operation. That is, one could interpret the unsustainable firm's debt policy as short-termism. Thus, access to debt financing decreases the advantage of the sustainable project over the unsustainable project through the leverage effect and hence discourages sustainable investing.

The result also implies that unrestricted lending can lead firms to invest in unsustainable projects. How can lenders prevent this negative impact of lending on ESG issues? In practice, some lenders refuse to finance unsustainable projects (i.e., negative screening for ESG issues). Naturally, such debt financing restrictions on unsustainable projects encourage sustainable investments as follows.

Remark 3 *Suppose that the firm is able to use debt financing only for the sustainable project. In this case, problem (23) is replaced with*

$$V^L(x) = \sup_T \mathbb{E}[\mathrm{e}^{-rT} \max\{a_1^U X(T) - I_1, a_2^L X(T) - I_2\}],$$

which can be solved in the same way as problem (23). Sustainability condition (24) is replaced with

$$\left(\frac{(r-\mu+\lambda)\phi_2}{r-\mu}\right)^{\frac{\beta}{\beta-1}} \geq \frac{I_2}{I_1},$$

which is more likely to hold than condition (3). That is, the firm is more likely to choose the sustainable project in the negative screening model than in the unlevered model.

4 Numerical illustrations

4.1 Impacts of ESG risk

This section conducts numerical analysis, including comparative statics with respect to key parameters: ESG risk λ, discount rate r, growth rate μ, volatility σ, and corporate tax rate τ. The

[8] Although I cannot analytically show $\mathrm{d}LV_1/\mathrm{d}\lambda > 0$, but Section 4 verifies $\mathrm{d}LV_1/\mathrm{d}\lambda > 0$ in numerical examples.

Table 1: Baseline parameter values.

r	μ	σ	τ	λ	α	I_1	I_2	x
0.05	0.01	0.2	0.15	0.1	0.4	10	100	0.5

baseline parameter values are set as in Table 1.[9] The values of r, μ, σ, τ, and α are standard in dynamic corporate finance literature and reflect a typical S&P firm (e.g., Morellec (2001), Arnold (2014), Shibata and Nishihara (2018), and Nishihara and Shibata (2021)). Following Boomsma and Linnerud (2015) and Adkins and Paxson (2016), who assume renewable energy policy uncertainty as a Poisson jump process with hazard rate 0.1, ESG risk is set at $\lambda = 0.1$. This means that the unsustainable project's lifetime is, on average, $1/\lambda = 10$ years. For instance, regulations for greenhouse gas emissions are greatly affected by international agreements, such as the Kyoto Protocol in 1997 and the Paris agreement in 2015, and the time span is about 10 to 20 years. Blowing up due to ESG concerns in social networks might occur more frequently, although it depends on the publicity of the firm or project. This subsection shows the results for $\lambda = 0$ to 0.2. The baseline case also assumes $x = X(0) = 0.5, I_1 = 10$, and $I_2 = 100$ to make the sustainable and unsustainable project values comparable. These values are not essential because they can be normalized. Note that the initial state variable $x = X(0) = 0.5$ is low enough to exclude immediate investment for all examples in this section.

For the baseline parameter values, sustainability conditions (3) and (24) are satisfied. The unlevered firm's value and investment threshold are $V^U(x) = 0.44$ and $x_2^U = 10.237$, whereas those of the levered firm are $V^L(x) = 0.482$ and $x_2^L = 9.745$, where the leverage effect $\phi_2 = 1.051$. In the levered case, the coupon, default threshold, leverage, and credit spreads are equal to $C_2(x_2^L) = 6.072, x_2^D(C_2(x_2^L)) = x_2^L/h_2 = 2.791, LV_2 = 0.485$, and $CS_2 = 0.0075$. Note that LV_2 and CS_2 are evaluated at the time of investment.

Figure 1 plots investment thresholds x^L, x^U, default threshold x^D, coupon C, firm values $V^L(x), V^U(x)$, leverage LV, and credit spreads CS for ESG risk $\lambda = 0$ to 0.2, where the black solid and blue dashed lines represent the levered and unlevered cases, respectively. Sustainability conditions (3) and (24) hold for $\lambda \geq 0.076$ and $\lambda \geq 0.078$, respectively. The two conditions are almost equal because the leverage effect on the choice is very weak (i.e., $\phi_2/\phi_1 \approx 1$). As shown in Proposition 2, higher λ decreases the NPV of the unsustainable project with no debt and thus induces the firm to choose the sustainable project. This holds true in the levered model because the impact of r on the NPV is much stronger the impact of λ on ϕ_2/ϕ_1.

Figure 1 shows the jumps in the graphs other than $V^L(x)$ and $V^U(x)$ at the switching points between the unsustainable and sustainable projects. For instance, sustainable investment thresholds x_2^L and x_2^U are much higher than unsustainable investment thresholds x_{11}^L and x_{11}^U even when the

[9] I computed the results for a wide range of parameter values and presented the qualitatively robust results in this section.

two project values are comparable. In fact, the firm postpones the sustainable project until the state process $X(t)$ reaches quite a high threshold because of its high-cost and high-profit structure. That is, sustainable investment timing is later than unsustainable investment timing when the choice between the two projects is comparable.

On the other hand, as explained in Remarks 1 and 2, ESG-unaware and ESG-motivated firms invest in the unsustainable and sustainable projects, respectively, at $x_3^U = 1.024$ in the unlevered case and $x_3^L = 0.975$ in the levered case. These thresholds agree with x^U and x^L for $\lambda = 0$ in the top-left panel of Figure 1. Compared to these values, the baseline (ESG-aware) firm's investment threshold is much higher especially in the case of sustainable investing. These results entail the following policy implication. The government's proactive stances on sustainability issues may be able to increase λ and I_2/I_1 and cause ESG-aware firms to switch from unsustainable projects to sustainable projects. In terms of investment timing, however, these sustainable investments will take place much later than unsustainable investments with comparable project values.

Now, I examine each panel of Figure 1 closely. All values are constant in the sustainable project region because the sustainable project does not depend on λ. In the unsustainable project region, $x_{11}^L, x_{11}^U, x_1^D, C_1, LV_1$, and CS_1 increase in λ, whereas $V_1^L(x)$ and $V_1^U(x)$ decrease in λ. The delay in investment and decrease in firm value are straightforward because the unsustainable NPV decreases with higher λ. What is more notable is the increase in LV_1 in the bottom-left panel of Figure 1. The reason has been already mentioned below Proposition 4. Higher λ decreases the probability of bankruptcy prior to the random maturity and hence decreases the expected bankruptcy costs. Accordingly, the firm adopts a more aggressive capital structure as λ increases. The increase in CS_1 in the bottom-right panel is due partially to the increase in LV_1, but the main driver is the increase of the forced exit probability (i.e., the second term of the numerator in (22)). These results predict a positive correlation between ESG risk and leverage (or credit spreads). In keeping with the prediction, many papers empirically show that bad ESG practices increase credit risk (see Table 4 in Gillan, Koch, and Starks (2021) and Seltzer, Starks, and Zhu (2022)). Although I could not find any empirical paper on the relationship between ESG and leverage, it will be an interesting issue for future empirical studies.

4.2 Impacts of discount rate

Apart from ESG risk λ, the discount rate r greatly affects the firm's choice between the sustainable and unsustainable projects. Intuitively, with high r, the firm focuses on cash flows in the near future and puts less weight on long-term sustainability of cash flows (i.e., short-termism). The firm with short-termism tends to prefer the unsustainable project. More precisely, Proposition 2 show the impact of r on the project choice thorough the NPV and option effects in the unlevered model. The impact of r remains unchanged in the levered model because the impact of r on the leverage effect (i.e., ϕ_2/ϕ_1) is relatively weak. Figure 2 plots $x^L, x^U, x^D, C, V^L(x), V^U(x), LV$, and CS for discount rate $r = 0.02$ to 0.08, where the black solid and blue dashed lines represent the levered and unlevered cases, respectively. Sustainability conditions (3) and (24) hold for $r \leq 0.0576$ and

$r \leq 0.0567$, respectively, where the graphs other than $V^L(x)$ and $V^U(x)$ jump at the switching points.

As explained below Proposition 4, low discount rate r is associated with large and listed firms, and low interest rate policies. In such situations, firms face fewer financial constraints and can easily use debt financing. Although unrestricted access to debt financing hinders sustainable investing (see Proposition 4), the impact through the leverage channel is much weaker than the impacts through the NPV and option channels. Overall, large and listed firms are likely to choose sustainable projects, and low interest rate policies help sustainable investment trends.

In each panel of Figure 2, the impacts of r are greater in the sustainable project region than in the unsustainable project region. The main reason is that the unsustainable project's cash flows may end in the short term and are less sensitive to the level of r. In the top-left panel, x^L and x^U jump downward at the switching points from the sustainable project to the unsustainable project, although $x^L_{11}, x^L_2, x^U_{11}$, and x^U_2 (i.e., x^L and x^U within each project region) increase in r. It is well known in real options theory that higher r reduces the NPV of long-term cash flows and delays investment (e.g., see Proposition 2 in Nishihara (2021) for a formal proof). This standard result does not hold due to the switch from the sustainable project to the unsustainable project. For instance, investment occurs earlier for $r = 0.06$ than for $r = 0.04$ because the firm invests in different projects for $r = 0.04$ and 0.06. This implies that low interest policies do not necessarily accelerate corporate investment.

In the center-right panel of Figure 2, $V^L(x)$ and $V^U(x)$ greatly decrease in r mainly because the project values are exponentially discounted by rate r. In the bottom-left panel, LV increases in r. This result is due to the effect of λ on the unsustainable firm's LV (cf. Figure 1 in Section 4.1). Indeed, with higher r, the firm puts less weight on bankruptcy costs in the future and increases leverage to receive the tax benefits. That is, the firm with short-termism adopts a riskier capital structure. This also increases CS in the bottom-right panel.

4.3 Impacts of cash flow growth rate

This subsection examines the comparative statics with respect to growth rate μ. Figure 3 plots $x^L, x^U, x^D, C, V^L(x), V^U(x), LV$, and CS for growth rate $\mu = 0$ to 0.04, where the black solid and blue dashed lines represent the levered and unlevered cases, respectively. Sustainability conditions (3) and (24) hold for $\mu \geq 0.0045$ and $\mu \geq 0.0051$, respectively, where the graphs other than $V^L(x)$ and $V^U(x)$ jump at the switching points. All else being equal, higher μ encourages sustainable investing. This results primarily from the NPV and option effects explained below Proposition 2, that is, higher μ, like r, increases the NPV of long-term cash flows and the option value of postponing investment. Note that the impact of μ on the leverage effect (i.e., ϕ_2/ϕ_1) is much weaker than the impact of μ on the NPV and option value. Empirical studies show mixed evidence of whether good ESG practices help firm performance (e.g., Table 5 in Gillan, Koch, and Starks (2021)). This paper reminds us of the importance of endogeneity for the research question. Indeed, the model indicates that firms that have high growth rates are more likely to invest in sustainable projects.

In the top-left panel of Figure 3, x^L and x^U increase in μ in the unsustainable project region but decrease in μ in the sustainable project region. The non-monotonic result is explained by the tradeoff between the NPV and option effects as follows. Higher μ increases the NPV of cash flows, which plays a role in accelerating investment. On the other hand, higher μ also increases the option value of waiting for a better economic state, which plays a role in delaying investment. The NPV effect (i.e., the investment acceleration effect) dominates the option effect (i.e., the investment delay effect) for the sustainable project with perpetual cash flows, and vice versa for the unsustainable project with short-term cash flows.

The bottom-left panel of Figure 3 also shows a notable result. Although LV_1 and LV_2 (i.e., LV within each project region) increase in μ, LV is not monotonic due to the switch between the unsustainable and sustainable projects. Most of the structural models (e.g., Leland (1994)) based on the tradeoff theory generate a positive relation between LV and μ, although empirical studies (e.g., Titman and Wessels (1988) and Frank and Goyal (2015)) show a negative relation. This paper shows the possibility that a firm with higher μ can invest in the sustainable project with lower LV than a firm with lower μ. For instance, the panel shows that LV for $\mu = 0$ to 0.0051 is higher than LV for $\mu = 0.0051$ to 0.04. That is, the model can generate a negative relation between LV and μ by incorporating an investment choice between sustainable and unsustainable projects.

4.4 Impacts of cash flow volatility

In the real option analysis, it is important to study the comparative statics with respect to σ because σ affects the results thorough the option channel rather than the NPV channel. As shown in Proposition 2, higher σ increases the value of the option to invest in the high-profit and high-cost project (i.e., the sustainable project) rather than the low-profit and low-cost project (i.e., the unsustainable project) in the unlevered model. This result holds true in the levered model because the impact of σ on the leverage effect (i.e., ϕ_2/ϕ_1) is relatively weak. Figure 4 plots $x^L, x^U, x^D, C, V^L(x), V^U(x), LV$, and CS for volatility $\sigma = 0.1$ to 0.5, where the black solid and blue dashed lines represent the levered and unlevered cases, respectively. Sustainability conditions (3) and (24) hold for $\sigma \geq 0.147$ and $\sigma \geq 0.152$, respectively, where the graphs other than $V^L(x)$ and $V^U(x)$ jump at the switching points.

Although the jumps are characteristic of a model with project choice, most of the other results are straightforward and consistent with the standard results in real options theory. For instance, $x^L, x^U, V^L(x)$, and $V^U(x)$ increase in σ in the top-left and center-right panels . This is consistent with the well-known result that higher σ increases the option value of waiting for a better economic state (e.g., Dixit and Pindyck (1994)). In the bottom-left panel, LV decreases in σ, which is consistent with the well-known result that higher σ increases bankruptcy risk and hence decreases leverage (e.g., Leland (1994)). Although x^D is not monotonic in the upper-right panel, it is not notable. In fact, the gap between x^L and x^D increases in σ, which is consistent with the standard result.

The bottom-right panel is most interesting in Figure 4. In the panel, CS_1 and CS_2 (i.e., CS within each project region) increase in σ. This is because adjustment of capital structure (i.e., a decrease in LV with higher σ) does not fully offset the increase in bankruptcy risk with higher σ. Although this result is consistent with the standard result in the capital structure literature (e.g., Leland (1994)), the switch between the unsustainable and sustainable projects changes the monotonic result. Note that CS_1 is much higher due to the forced exit risk (i.e., the second term of the numerator in (22)) than CS_2. Lower σ can cause the firm to choose the unsustainable project and hence increase CS. In fact, in the bottom-right panel, CS is higher for $\sigma = 0.1$ to 0.152 than for $\sigma = 0.152$ to 0.5. This counter-intuitive result may warn against the apparent argument that a less volatile economy encourages stable development and hence improves sustainability. Indeed, the model indicates the opposite possibility, that is, lower σ discourages sustainable investments and increases corporate bankruptcies.

4.5 Impacts of corporate tax rate

It is also interesting to study the effects of corporate tax rate τ on the results in terms of policy implications. Obviously, tax reductions only for sustainable projects, like subsidies, reduce investment cost I_2 and encourage sustainable investing. The question is as to whether lower taxation of firms encourages sustainable investing. Sustainability condition (3) does not depend on τ in the unlevered model, while sustainability condition (24) depends on τ through the leverage effect ϕ_2/ϕ_1. In other words, τ affects the choice between the sustainable and unsustainable projects only through the capital structure channel. As seen in the previous subsections, ϕ_2/ϕ_1 does not change greatly with parameters. Even though τ significantly affects the capital structure in tradeoff theory, ϕ_2/ϕ_1changes from 0.993 to 0.935 with variation of $\tau = 0.05$ to 0.55. Because of the small impact of τ on ϕ_2/ϕ_1, sustainability condition (24) holds for $\tau = 0.05$ to 0.55. To see the weak impacts of τ on the sustainability choice, I reset $I_2 = 140$, where the other parameter values remain as in Table 1. Note that the sustainable and unsustainable project values are almost equal for $I_2 = 140$.

Figure 5 plots $x^L, x^U, x^D, C, V^L(x), V^U(x), LV$, and CS for corporate tax rate $\tau = 0.05$ to 0.55, where the black solid and blue dashed lines represent the levered and unlevered cases, respectively. Sustainability condition (3) holds true regardless of τ in the unlevered model, while sustainability condition (24) hold for $\tau \leq 0.307$, where the graphs other than $V^L(x)$ jump at the switching points. This result implies that lower τ encourages sustainable investing. The reason is explained as follows. According to tradeoff theory, lower τ reduces the tax advantages of debt and hence reduce LV (see the bottom-left panel of Figure 5). That is, the firm is less leveraged and approximates the unlevered firm as τ decreases. As explained in Proposition 4, the unleverd firm is more likely to choose the sustainable project than the highly levered firm is. Thus, lower τ encourages sustainable investing by decreasing LV. As a policy implication, tax reductions could lead to safer capital structure and encourage sustainable investing, although the effects on sustainability through capital structure are indirect and weaker than the NPV and option effects. Note that this result is based on permanently lower levels of corporate tax rates. Tax reductions for a short period can discourage sustainable investing because the firm focuses on short-term cash flows rather than long-term cash flows.

The center-right panel of Figure 5 shows that $V^L(x)$ and $V^U(x)$ decrease in τ. The results are straightforward because higher τ decreases the NPV of cash flows. More interestingly, the gap between $V^L(x)$ and $V^U(x)$ increases in τ. In fact, $V^U(x)$ decreases almost linearly, but the slope of $V^L(x)$ moderates, especially after the switching point $\tau = 0.307$. That is, the levered firm mitigates the negative impact of higher τ by choosing the unsustainable project and higher LV (see the bottom-left panel) with greater tax advantages. In the top-left panel, x^L jumps downward at the switching point from the sustainable project to the unsustainable project, whereas x^L_{11}, x^L_2 (i.e., x^L within each project region), and $x^U = x^U_2$ increase in τ. The monotonic increase within each region is explained by the straightforward effect that higher τ decreases the NPV of cash flows and delays investment. However, in the levered model, the monotonic result does not hold due to the switch from the sustainable project to the unsustainable project. In fact, x^L is higher for $\tau = 0.05$ to 0.307 than for $\tau = 0.307$ to 0.55. This implies that low tax rate policies may improve corporate sustainability but delay corporate investment.

5 Conclusion

This paper investigates a firm's choice of project sustainability, investment timing, and capital structure in the real options model. In the model, the firm chooses between sustainable and unsustainable projects, where the sustainable project with high investment cost yields perpetual cash flows, but the unsustainable project with low investment cost has risk of cash flow termination (i.e., ESG risk). This paper analytically derives the unlevered and levered model solutions including the sustainability conditions and shows the effects of key parameters on the results. The main results are summarized below.

With higher ESG risk, lower discount rate, and higher growth rate, the firm is more likely to invest in the sustainable project mainly because these factors increase the advantage of the sustainable NPV over the unsustainable NPV. Higher volatility encourages sustainable investing mainly through the option effect. The firm with a less sustainable project can increase its value by adopting more leverage because bankruptcy costs matter less. This means that the leverage effect is larger for the less sustainable firm. Through the leverage effect, access to debt financing decreases the advantage of the sustainable project over the unsustainable project and hence discourages sustainable investing. A higher corporate tax rate can also discourage sustainable investing through the leverage effect, but the leverage effect is weaker than the NPV and option effects.

These results clarify the market conditions and firm characteristics that promote sustainable investing and entail many policy implications. However, it must be noted that parameter shifts (e.g., market and policy shifts) that encourage sustainable investing do not necessarily accelerate investment because sustainable investment timing is later than unsustainable investment timing, due to higher investment cost. For instance, contrary to straightforward expectations, lower discount rate and higher growth rate can delay corporate investment through switch from the unsustainable investment to the sustainable investment.

A Proof of Proposition 1

It is easy to show that the value function (4) with investment threshold (5) is the solution to the problem with only the sustainable project, i.e., $\sup_{T\in\mathcal{T}}\mathbb{E}[\mathrm{e}^{-rT}(a_2^U X(T)-I_2)]$.

Define $f(x)=(4)-(a_1^U x-I_1)$. Below, I will show that $f(x)\geq 0$ holds for all $x\geq 0$ if and only if condition (3) holds. The solution to $f'(x^*)=0$ becomes $x^*=x_2^U(a_1/a_2)^{1/(\beta-1)}\in(0,x_2^U)$. Note that $f(x)$ is convex because of $\beta>1$. Therefore, by the first-order condition, I have

$$\begin{aligned}\min_{x\geq 0} f(x) &= f(x^*)\\ &= (a_2^U x_2^U - I_2)\left(\frac{a_1^U}{a_2^U}\right)^{\frac{\beta}{\beta-1}} - a_1^U x_2^U\left(\frac{a_1^U}{a_2^U}\right)^{\frac{1}{\beta-1}} + I_1\\ &= I_1 - I_2\left(\frac{a_1^U}{a_2^U}\right)^{\frac{\beta}{\beta-1}},\end{aligned}$$

which is nonnegative if and only if condition (3) holds.

Under condition (3), the value function (4) dominates the payoff of the unsustainable project, and hence, the firm has no possibility of investing in the unsustainable project. Then, problem is reduced to $\sup_{T\in\mathcal{T}}\mathbb{E}[\mathrm{e}^{-rT}(a_2^U X(T)-I_2)]$, and the solution is (4).

Next, assume that condition (3) does not hold. In this case, the firm has a possibility of investing in the unsustainable project because of $f(x^*)<0$. On the other hand, $a_2^U x-I_2>a_1^U x-I_1$ holds for $x\to\infty$. Then, I can conjecture the two stopping regions, namely the unsustainable investment region $[x_{11}^U,x_{12}^U]$ and sustainable investment region $[x_{21}^U,\infty)$, where $x_{12}^U<x_{21}^U$. This conjecture is verified in Décamps, Mariotti, and Villeneuve (2006). By the value matching conditions at thresholds x_{11}^U, x_{12}^U, and x_{21}^U, the value function is expressed as (6), and the state prices are defined by

$$\Delta^U(x)=\frac{x^\beta (x_{21}^U)^{\gamma_2}-(x_{21}^U)^\beta x^{\gamma_2}}{(x_{12}^U)^\beta (x_{21}^U)^{\gamma_2}-(x_{21}^U)^\beta (x_{12}^U)^{\gamma_2}}, \tag{29}$$

$$\Sigma^U(x)=\frac{(x_{12}^U)^\beta x^{\gamma_2}-x^\beta (x_{12}^U)^{\gamma_2}}{(x_{12}^U)^\beta (x_{21}^U)^{\gamma_2}-(x_{21}^U)^\beta (x_{12}^U)^{\gamma_2}}, \tag{30}$$

where γ_2 represents the negative characteristic root $\gamma_2=0.5-\mu/\sigma^2-\sqrt{(\mu/\sigma^2-0.5)^2+2r/\sigma^2}$. Note that $\Delta(x)$ and $\Sigma(x)$ stand for the present values of \$1 contingent on the unsustainable investment and sustainable investment, respectively. Equation (7) follows from the smooth pasting condition at x_{11}^U. Thresholds x_{12}^U and x_{21}^U are determined by the smooth pasting conditions:

$$(a_1^U x_{12}^U - I_1)(\Delta^U)'(x_{12}^U)+(a_2^U x_{21}^U - I_2)(\Sigma^U)'(x_{12}^U)=a_1^U, \tag{31}$$

$$(a_1^U x_{12}^U - I_1)(\Delta^U)'(x_{21}^U)+(a_2^U x_{21}^U - I_2)(\Sigma^U)'(x_{21}^U)=a_2^U. \tag{32}$$

B Proof of Proposition 2

Clearly, higher I_1, λ, and lower I_2 expand region (3). Higher σ increases $\beta/(\beta-1)$ because of $\partial\beta/\partial\sigma < 0$.[10] Then, higher σ expands the region (3). Higher μ and lower r increase $(r-\mu+\lambda)/(r-\mu)$ as far as $r > \mu$ is satisfied. Higher μ and lower r also increases $\beta/(\beta-1)$ because of $\partial\beta/\partial\mu < 0$ and $\partial\beta/\partial r > 0$. Then, higher μ and lower r expands the region (3).

Note that investment thresholds (5) and (7) are $\beta/(\beta-1)$ times the zero-NPV thresholds, and higher $\beta/(\beta-1)$ means the higher value of waiting. Thus, I can state that σ affects sustainability condition (3) through the option effect, whereas μ and r affects (3) through the NPV and option effects.

C Proof of Proposition 3

I can trace the proof in Appendix A by replacing a_1^U and a_2^U with a_1^L and a_2^L respectively, and hence the proof is omitted. Sustainability condition (24) follows from $a_2^L/a_1^L = (r-\mu+\lambda)\phi_2/((r-\mu)\phi_1)$. The state prices $\Delta^L(x)$ and $\Sigma^L(x)$ are defined by

$$\Delta^L(x) = \frac{x^\beta (x_{21}^L)^{\gamma_2} - (x_{21}^L)^\beta x^{\gamma_2}}{(x_{12}^L)^\beta (x_{21}^L)^{\gamma_2} - (x_{21}^L)^\beta (x_{12}^L)^{\gamma_2}}, \tag{33}$$

$$\Sigma^L(x) = \frac{(x_{12}^L)^\beta x^{\gamma_2} - x^\beta (x_{12}^L)^{\gamma_2}}{(x_{12}^L)^\beta (x_{21}^L)^{\gamma_2} - (x_{21}^L)^\beta (x_{12}^L)^{\gamma_2}}. \tag{34}$$

Thresholds x_{12}^L and x_{21}^L are determined by the smooth pasting conditions:

$$(a_1^L x_{12}^L - I_1)(\Delta^L)'(x_{12}^L) + (a_2^L x_{21}^L - I_2)(\Sigma^L)'(x_{12}^L) = a_1^L, \tag{35}$$

$$(a_1^L x_{12}^L - I_1)(\Delta^L)'(x_{21}^L) + (a_2^L x_{21}^L - I_2)(\Sigma^L)'(x_{21}^L) = a_2^L. \tag{36}$$

D Proof of Proposition 4

Clearly, $\partial\phi_1/\partial h_1 < 0$ holds in (20), and $\partial\gamma_1/\lambda < 0$ holds in (12). Then, it is sufficient to show that $\partial h_1/\partial\gamma_1 > 0$. Simplify the notation by defining the function $h_1(\gamma_1) = (1-A\gamma_1)^{1/\gamma_1}$ for $\gamma_1 < 0$, where A is a positive constant. By calculating the derivative, I have

$$h_1'(\gamma_1) = \frac{h_1(\gamma_1)}{\gamma_1^2}\left(\ln(1-A\gamma_1) + \frac{A\gamma_1}{1-A\gamma_1}\right). \tag{37}$$

Define

$$g(\gamma_1) = \ln(1-A\gamma_1) + \frac{A\gamma_1}{1-A\gamma_1}$$

and calculate the derivative

$$g'(\gamma_1) = \frac{A^2\gamma_1}{(1-A\gamma_1)^2} < 0 \ (\gamma_1 < 0).$$

Then, $g(\gamma_1) > g(0) = 0$ holds for all $\gamma_1 < 0$, which implies $h_1'(\gamma_1) > 0$ in (37).

[10] The sensitivities of β to σ, μ, and r are well known (e.g., see Dixit and Pindyck (1994)).

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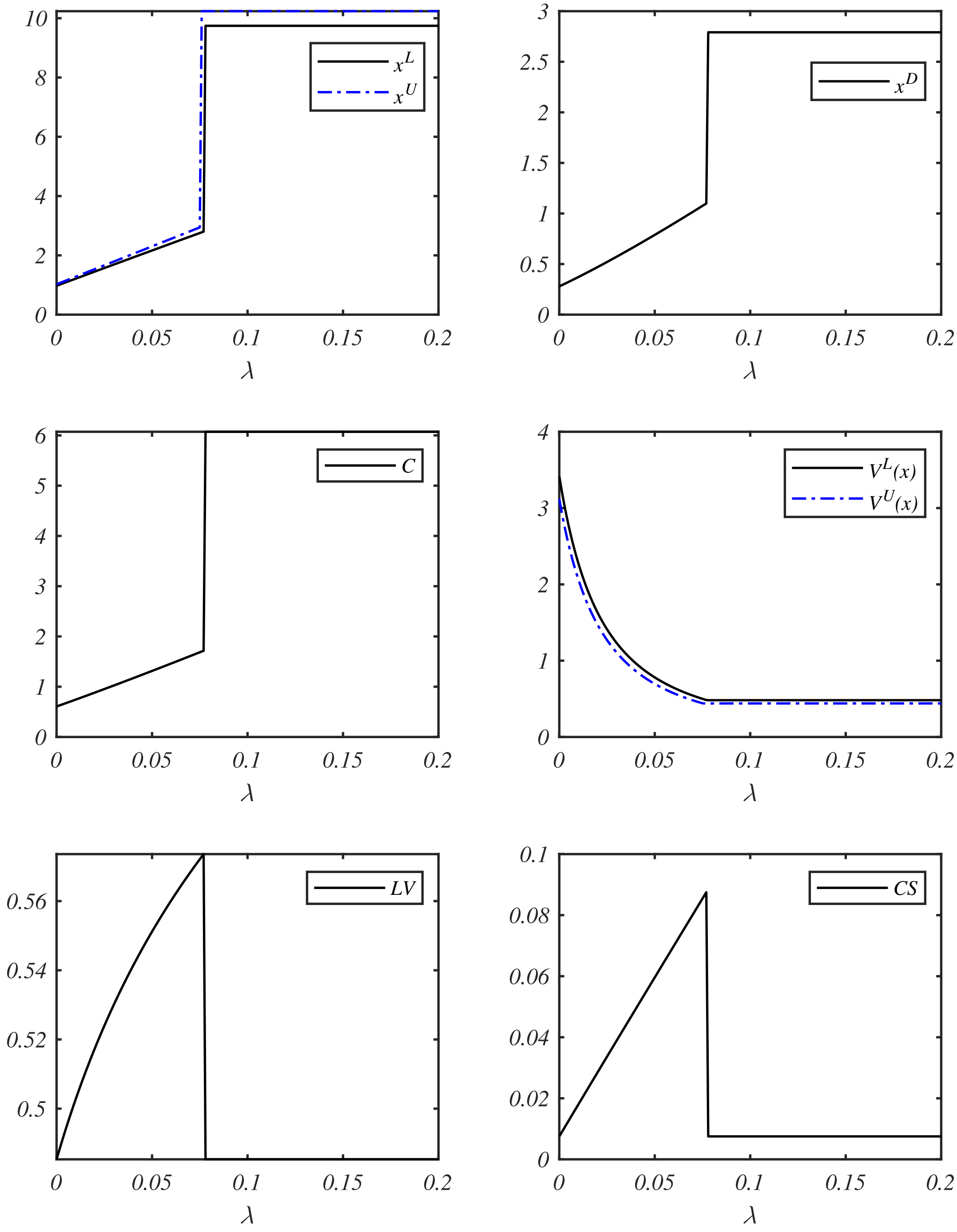

Figure 1: Comparative statics with respect to sustainability parameter λ.

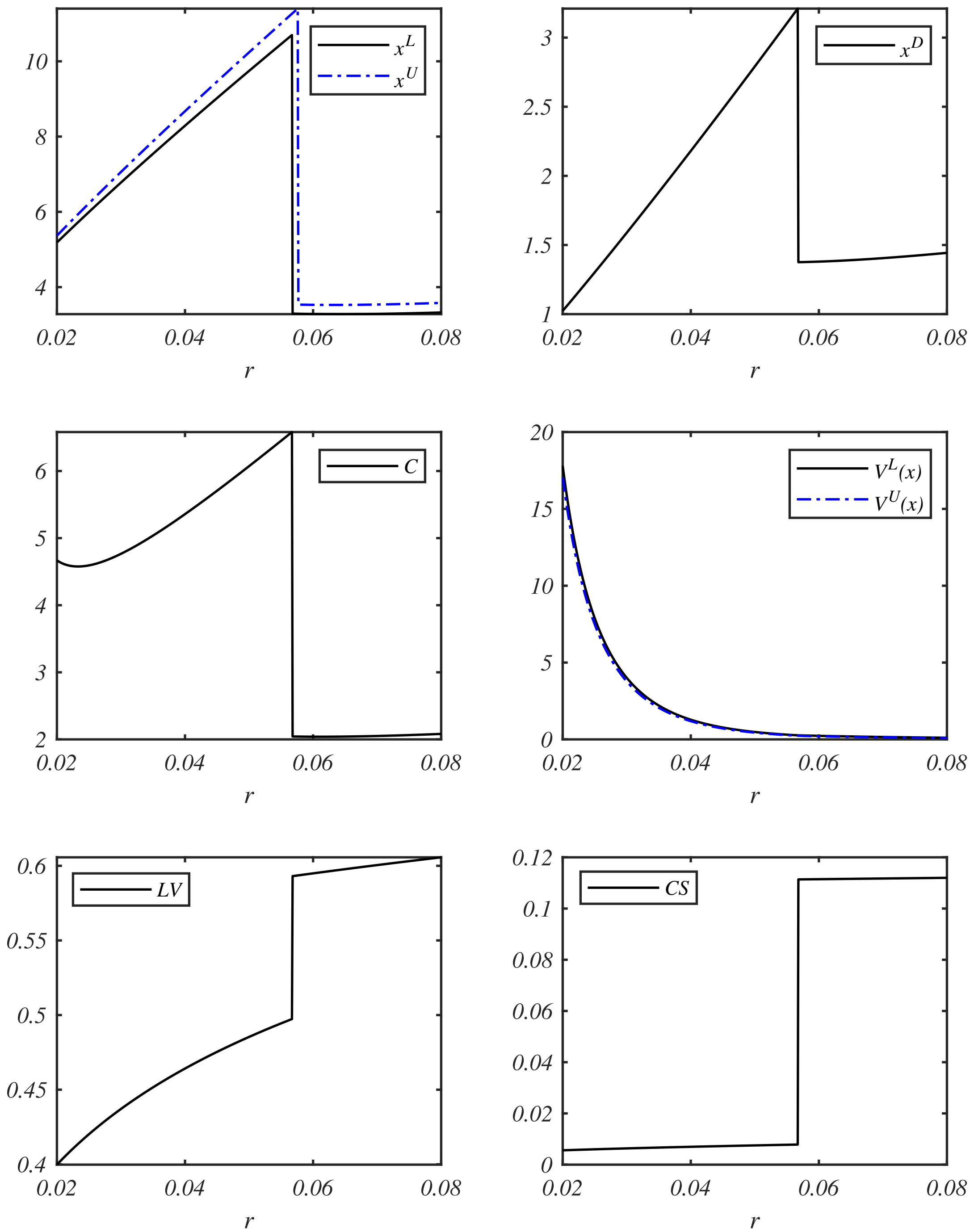

Figure 2: Comparative statics with respect to discount rate r.

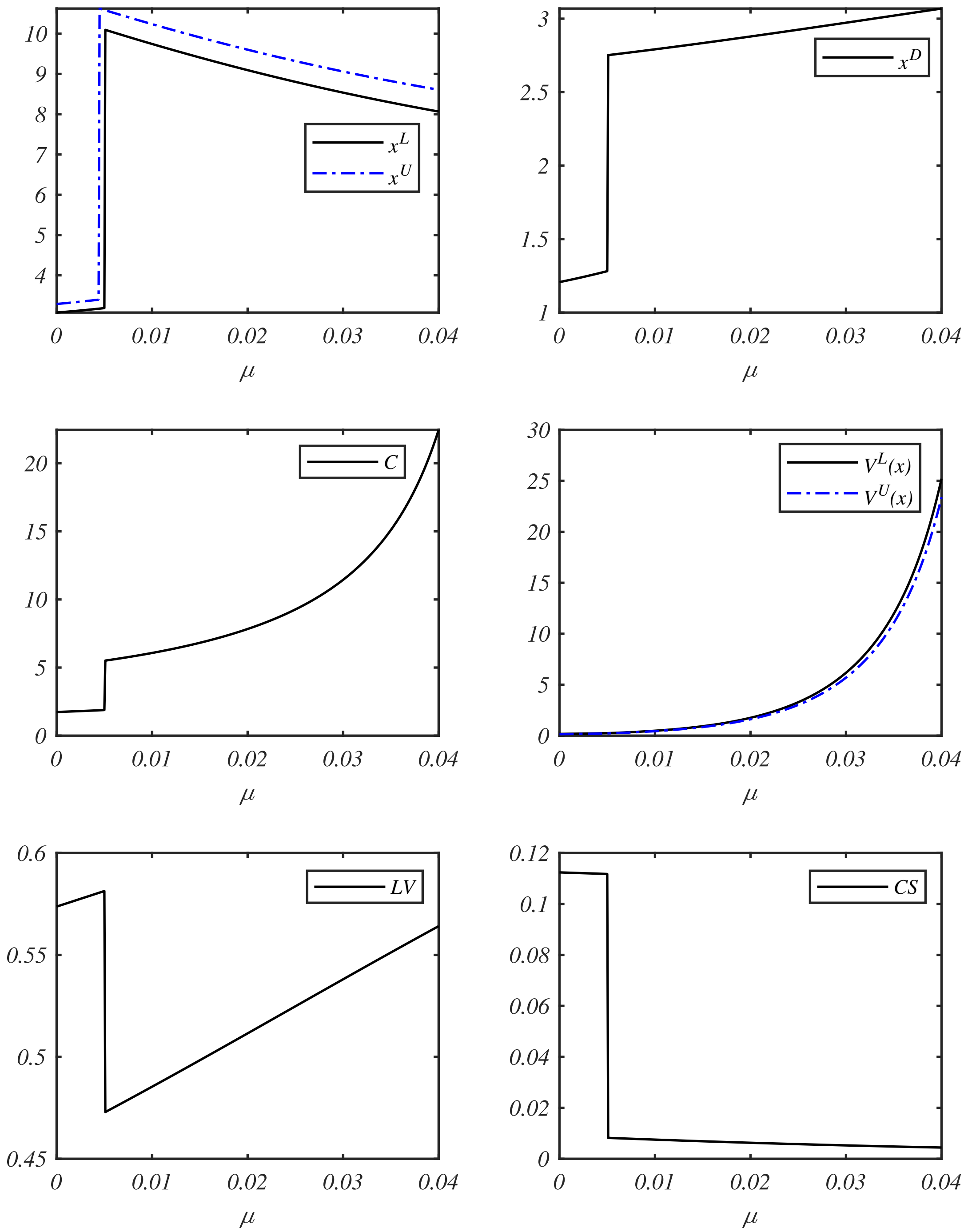

Figure 3: Comparative statics with respect to growth rate μ.

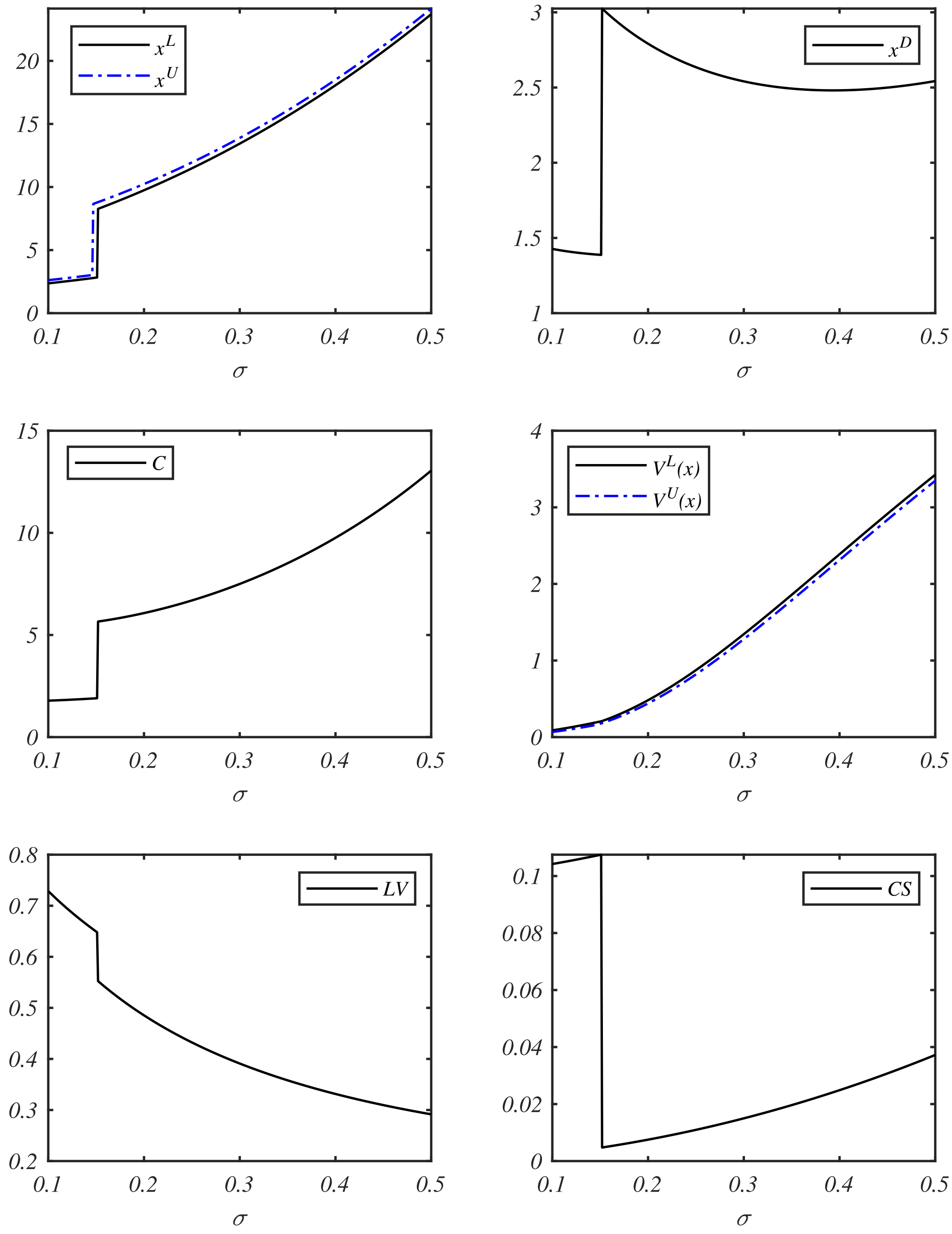

Figure 4: Comparative statics with respect to volatility σ.

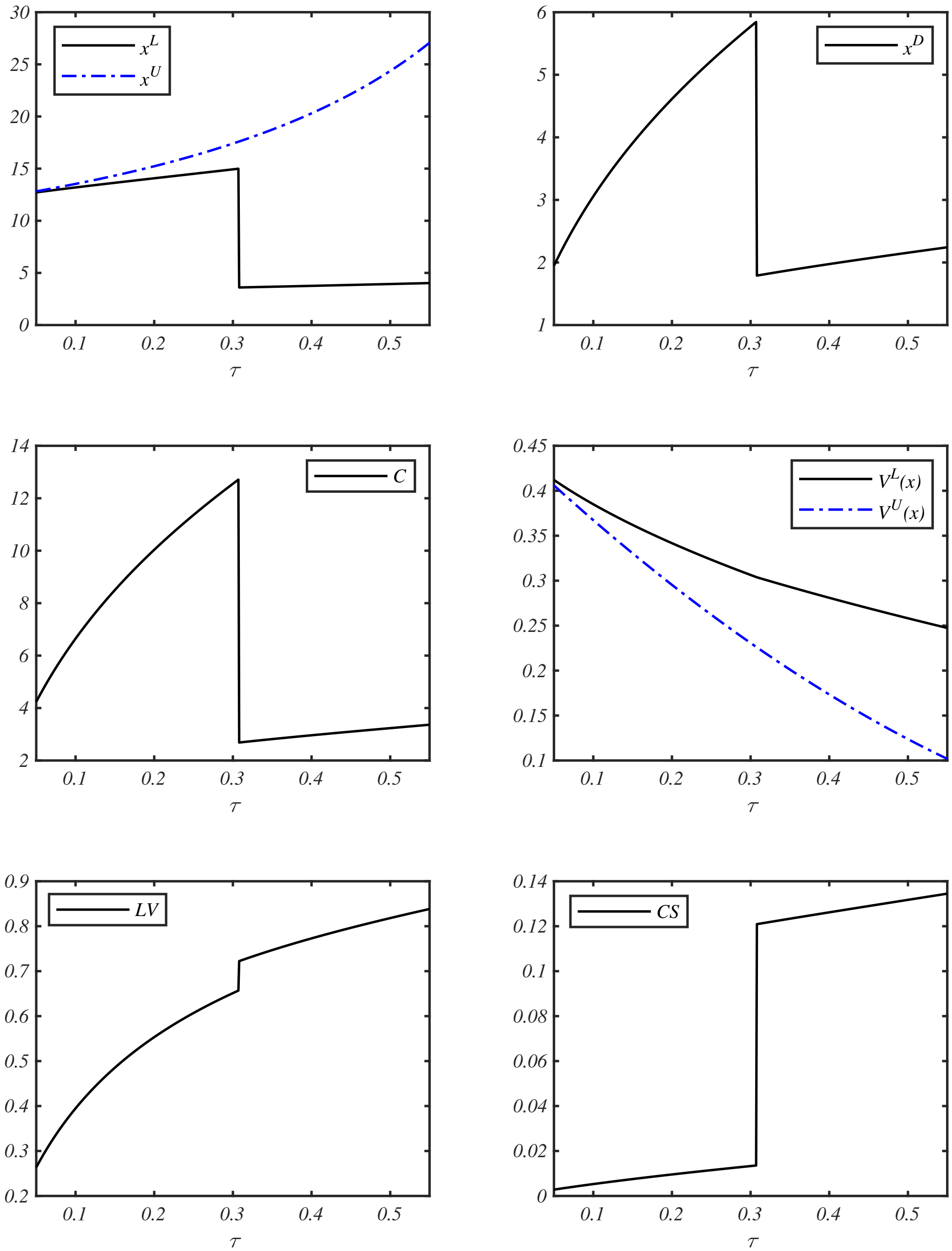

Figure 5: Comparative statics with respect to corporate tax rate τ. $I_2 = 140$.