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Investment and information asymmetry in corporate sustainability: Incentive-auditing contracts and policy insights☆

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ABSTRACT

This paper develops a real options model incorporating incentive-auditing contracts to address principal–agent challenges in ESG investments arising from information asymmetry. The model promotes honest reporting by managers through tailored incentives and auditing mechanisms, while also introducing a subsidy policy to evaluate its effects on contracts and social welfare. Our results reveal a paradox in optimal contracts: incentives may inadvertently favor unsustainable projects by mitigating information costs, thereby delaying sustainable investments. Enhanced corporate transparency is associated with reduced incentives, a lower investment threshold for sustainable projects, and an increased option value for owners but a decreased one for managers. Interestingly, moderate transparency reduces social welfare due to rising auditing costs, whereas both very high and very low transparency levels yield improved social welfare outcomes. Subsidy policies further bolster sustainable investment, especially in low-transparency settings, and modify the impact of transparency on owners' option value.

1. Introduction

In the past decade, the field of sustainable investment, often referred to as sustainable and responsible investment (SRI), has experienced a significant and steady rise in interest. SRI is an investment paradigm that is future oriented, integrating environmental, social, and governance (ESG) criteria into the comprehensive process of researching, analyzing, and selecting securities for an investment portfolio (Eurosif - The European Sustainable Investment Forum, 2018). This approach not only leverages traditional fundamental analysis but also actively engages with companies, assessing their ESG performance to enhance the potential for long-term financial returns. Concurrently, SRI aims to contribute positively to societal development by shaping corporate behavior towards more sustainable practices. Within this context, a considerable number of studies have examined various facets of sustainability. Specifically, in finance, research has explored sustainable investment or ESG investment (e.g., Avramov et al. (2022), Bolton and Kacperczyk (2021), Halbritter and Dorfleitner (2015) and Pedersen et al. (2021)). The extant literature has predominantly explored the interconnections between ESG performance, firm characteristics, firm risk, and firm value (for a survey, see Gillan et al. (2021)).

However, some studies have suggested that ESG disclosure practices may exacerbate information asymmetry due to the lack of a shared understanding of ESG metrics and their interpretation (Agapova et al., 2025; Christensen et al., 2022; Kimbrough et al., 2024). This situation enables firms to selectively disclose positive information while concealing negative data, such as carbon emissions and supply chain labor issues, thereby making it difficult for investors to accurately assess a company's true ESG performance (green washing). Similarly, information asymmetry often arises in sustainable investment, leading to principal–agent problems. Managers may exploit this opacity to misreport ESG performance for personal gain. For instance, they might misclassify non-ESG projects as ESG initiatives to exploit investment cost differentials for private profit or overstate environmental compliance to qualify for ESG subsidies (e.g., green tax credits). Additionally, managers could inflate social equity metrics to attract ESG-focused investors, thereby artificially boosting company valuation. Conversely, managers could underreport governance risks (e.g., internal fraud incidents) to avoid regulatory penalties or shareholder backlash. Such misreporting distorts investment decisions, as owners face inflated project valuations and hidden sustainability risks, ultimately undermining the

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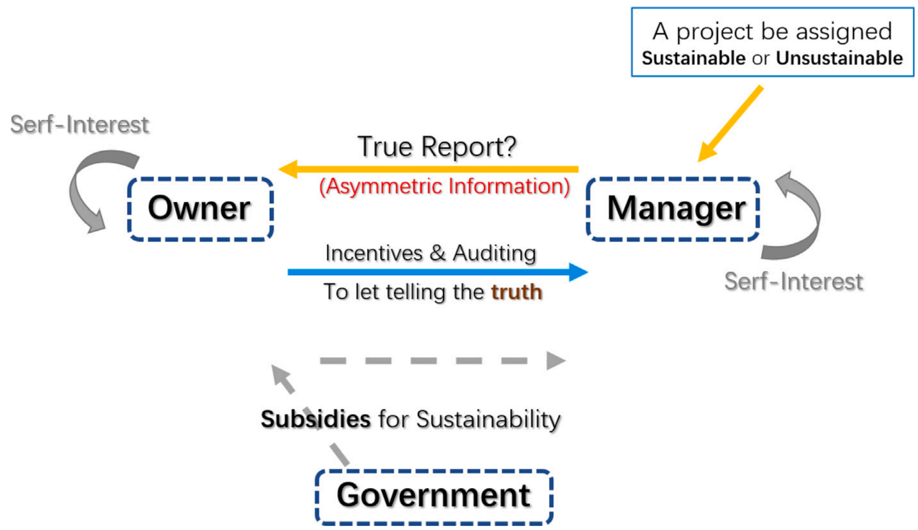


Fig. 1. This diagram illustrates the contractual and informational interactions among the key economic agents involved in ESG investment decisions. The owner delegates investment authority to the manager, who privately observes the project's ESG type and makes reporting and timing decisions. The owner designs an incentive-auditing contract to elicit truthful reporting, while the government provides subsidies conditional on verifiable sustainability. Information asymmetry, incentive compatibility, audit probability, and subsidy allocation jointly determine the investment threshold and social welfare outcomes.

alignment between ESG goals and corporate actions. Research on the agency problems within sustainable investment remains limited. Zhang and Yang (2024) were the first to address incentive contracts under information asymmetry considering ESG investing, but they do not account for auditing within corporate governance or the timing of investment decisions. This paper seeks to fill this research gap. To the best of our knowledge, we are the first to develop a dynamic contract model for sustainable investment that incorporates investment timing, incentives, and auditing. Additionally, we examine how government subsidies for sustainable investment influence investment decisions and social welfare.

In our model, a firm faces a decision to invest in one of two projects: sustainable or unsustainable. This involves a trade-off between ESG risk and investment cost. The sustainable project demands a higher investment cost but offers more enduring cash flows, with a longer expected maturity. Conversely, the unsustainable project requires a lower investment cost and provides cash flows up to a random maturity, expectedly sooner. The maturity follows a Poisson arrival process indicative of ESG risk. The firm assesses these trade-offs to optimize its investment decision and timing, aiming to maximize financial value.[1] We assume the cash flows of each project are observable by both owners and managers, whereas the ESG risk is private information, observable only by the managers. This information asymmetry creates motivation for managers to misreport, disguising an unsustainable project as a sustainable one to capture the difference in investment costs as personal gain. This leads to a principal–agent problem. Hence, it is necessary to design an incentive-auditing contract model to prevent such behavior. We propose such a model, solve it analytically, and derive the explicit conditions needed to assess the effectiveness of incentive-auditing contracts. We design an information asymmetry level k to quantify the transparency in corporate governance, which is used to examine the effectiveness of the contract model analytically and numerically. We also incorporate a government subsidy policy aimed at sustainable investment to further analyze the impact of this mechanism on investment decisions and social welfare. Fig. 1 visually summarizes the interactions and relationships between the various economic agents involved in this model.

[1] This model set is based on Nishihara (2024), we focuses on an firm that recognizes ESG risk and maximizes financial value.

Certain practical examples can validate the model. Imagine a food company planning to invest in a new agricultural project. Conventional farming may involve the heavy use of chemical fertilizers and pesticides, creating negative environmental and health impacts. However, sustainable agriculture (e.g., organic farming), although costlier, reduces environmental risks and enhances product competitiveness. The company must decide on the investment timing based on market demand and consumer preferences. In this scenario, managers may falsely claim to use sustainable organic methods while employing cheaper conventional inputs to cut costs and reap private gains. Another example is a retail corporation establishing new supply chains in developing countries. Traditional supply chains may involve labor exploitation and opaque production conditions, whereas implementing transparent supply chains (e.g., through blockchain tracking) requires higher costs but reduces reputational and legal risks. Managers could potentially conceal unethical labor practices to lower costs, creating information asymmetry and agency problems. Similarly, an oil pipeline project presents a classic case. Although traditional pipelines carry environmental risks like oil spills, the company could adopt more expensive but eco-friendly technologies (e.g., thicker walls with advanced leak detection systems). Managers might cut corners during construction while reporting full compliance, knowing regulators and investors cannot easily verify actual implementation quality. Shorter-lived projects may also qualify as ESG-compliant ones. For instance, rapid-degradable packaging R&D, such as seaweed-based films replacing plastics, delivers concentrated environmental benefits despite technological obsolescence risks, aligning with regulations like the EU Single-Use Plastics Directive. Similarly, low-carbon mega-events (e.g., "Zero Waste Plan") validate transient ESG value through verifiable metrics, although managers may overstate legacy impacts to mask short-term cost-cutting. These cases underscore our model's capacity to evaluate ESG alignment via auditing-driven accountability, even for ephemeral initiatives.

We derive the baseline solutions for incentive-auditing contract design under information asymmetry and the subsidy solutions introduced with the implementation of a subsidy policy. The baseline results reveal challenges for ESG investments. Optimal contracts paradoxically incentivize managers of unsustainable projects, whereas sustainable investments are delayed due to information asymmetry. Higher corporate transparency correlates with lower incentives and lower investment thresholds, enhancing owners' but diminishing managers' option values. Moderate transparency incurs the highest auditing costs, counterintuitively minimizing social welfare, whereas higher or lower levels can improve it. Also, we found that a higher probability of drawing sustainable projects leads to favorable outcomes such as reduced thresholds and audit expenses, increased incentives, and enhanced social welfare. Concerning the subsidy solutions, subsidies emerge as a policy lever for ESG investment promotion. They expedite sustainable project initiation and are especially impactful in low-transparent corporate governance, mitigating governance opacity's negative effects. Both owners and managers gain from subsidies, with an unexpected finding that subsidies invert the impact of corporate transparency on the owner's option value.

This study presents several key implications for the design of contracts and policies to enhance corporate sustainability. First, it underscores the counterintuitive nature of optimal contracts, which may inadvertently favor unsustainable projects, highlighting a need to realign incentives with ESG principles. Second, higher corporate transparency is associated with faster sustainable investment, yet it can lead paradoxically to lower social welfare at moderate levels due to increased auditing costs. Third, subsidy policies are shown to be instrumental in accelerating sustainable investments, particularly in less transparent corporate governance, and in altering the dynamics of corporate transparency's impact on owner value. The research suggests that a higher probability of selecting sustainable projects lowers the investment threshold, increases incentives, and enhances social welfare, albeit with a complex relationship with managerial value. Additionally, we find that greater cash flow volatility increases option value and social welfare while reducing the effectiveness of incentive and auditing mechanisms at extreme levels, emphasizing the importance of contract design under uncertainty. These findings provide actionable insights into how managerial incentives, the auditing system, and subsidies can be structured to align corporate behavior with ESG goals and improve social welfare.

The remainder of this paper is structured as follows: Section 2 reviews recent relevant literature. Section 3 introduces the model setup. Section 4 presents the model solutions. Section 5 numerically explores the solutions, focusing on the information asymmetry level in corporate governance, and discusses the effectiveness of the incentive-auditing mechanism across various cases, as well as the impact on option value, social welfare, and the effects of the subsidy policy. Finally, Section 6 concludes the paper, offering implications, limitations, and future research directions.

2. Literature review

2.1. ESG investment and firm outcomes

A growing body of research in finance has explored how integrating ESG factors into corporate strategy affects firm value and risk. Starks (2023) emphasizes the divergence between investor and managerial motivations around "value" versus "values", and calls for more rigorous analysis of ESG's economic impact. Empirical studies generally suggest that strong ESG performance enhances firm resilience. Lins et al. (2017) find that firms with high social capital outperformed during the 2008–2009 financial crisis. Albuquerque et al. (2019) argue that ESG-oriented firms benefit from more inelastic demand due to product differentiation, reducing systematic risk. Similarly, El Ghoul et al. (2011) and Hong and Kacperczyk (2009) find that responsible ESG behavior lowers financing costs through broader investor bases and reduced litigation risk. Seltzer et al. (2022) show that poor environmental performance leads to higher bond spreads and lower credit ratings, particularly under stricter regulatory environments.

Other studies have highlighted the asymmetric benefits of ESG during crises. For instance, Atz et al. (2023) suggest that ESG investments may not consistently outperform traditional assets but provide downside protection in turbulent times. These findings collectively underscore that ESG integration can increase firm value, reduce capital costs, and improve risk-adjusted returns. However, many of these studies assume ESG attributes are observable. In reality, ESG-related information is often private or imperfectly disclosed, giving rise to agency concerns.

2.2. Information asymmetry and ESG-related agency problems

Although ESG investments have the potential to create long-term value, they also generate agency problems under asymmetric information. Managers typically possess superior knowledge about project sustainability, which may lead to either underinvestment or misreporting. Ofir and Elmakiess (2023) term this misalignment the "eco-agency problem", where managers may avoid ESG investments with deferred payoffs, conflicting with stakeholders' long-term interests. Bilyay-Erdogan et al. (2024) find that ESG performance and information asymmetry jointly shape investment efficiency. When ESG disclosure is weak, managers may pursue symbolic ESG initiatives or "greenwash" actual performance. Empirically, firms with higher transparency and ESG credibility tend to face lower capital market information asymmetry (Cui et al., 2018; Niu et al., 2024). Cespa and Cestone (2007) and Hussaini et al. (2021) argue managers can strategically use CSR to entrench themselves, whereas other studies find that strong governance aligns ESG with value maximization. Overall, the literature highlights that insufficient transparency and misaligned incentives can lead to either ESG underinvestment or symbolic compliance. Our model is motivated by the need to understand how well-designed contracts can address ESG-related agency problems in such settings.

2.3. Incentive contracts under information asymmetry

Our approach draws upon real options and contract theory in the presence of hidden information. Grenadier and Wang (2005) develop a principal–agent model where a firm owner delegates investment timing to a privately informed manager. They show that without corrective mechanisms, managers delay investment relative to the socially optimal timing. To restore efficiency, optimal contracts must reward truthful disclosure and effort.

Nishihara and Shibata (2008) extend this by incorporating auditing and penalties alongside bonuses, demonstrating that a well-calibrated incentive-auditing contract can deter misreporting and restore timely investment. The use of probabilistic auditing adds realism and policy relevance, as perfect enforcement is often infeasible. Our model follows this tradition by incorporating misreporting penalties and performance-based incentives, tailored to an ESG setting where project type (sustainable vs. unsustainable) is not publicly observable. Unlike earlier work, we explicitly study how these contract structures interact with policy tools (e.g., subsidies) and how ESG-specific risk characteristics alter the optimal mechanism design.

2.4. Government subsidies and sustainable investment

In parallel with corporate governance solutions, government subsidies play an essential role in promoting sustainable investment. Many countries employ tax credits, direct grants, and other incentives to correct market failures and encourage ESG-aligned capital allocation. Azhgaliyeva et al. (2020), Chen and Zhao (2021), and Kosztowniak (2023) show that green bonds and tax incentives have helped scale investment in renewable energy and energy-efficient infrastructure. According to the World Bank, the global adoption of green subsidy programs has risen substantially since 2008.[2]

However, the effectiveness of such programs depends critically on corporate transparency and implementation integrity. Peng and Sun (2024) and Zhang et al. (2023) find that subsidies can improve ESG performance, particularly when transparency is high and governance is strong. Conversely, subsidies without accountability mechanisms risk being captured by self-interested managers, especially in low-transparency environments. Our model contributes to this literature by

[2] See World Bank: Green Subsidies and Climate Strategy, further discussion is in Section 3.2.

explicitly modeling how government subsidies interact with managerial incentives and information asymmetry. We show that although subsidies can accelerate ESG investment, they must be carefully designed to avoid distorting reporting behavior and undermining governance goals. This connection between public policy and private contracting represents a critical area for both theoretical exploration and empirical validation.

3. Model setup

In this section, we present the real options model framework addressing the principal–agent problem in the context of asymmetric information under sustainability. Dixit and Pindyck (1994) and Trigeorgis (1996) provide an adequate summary of the real options approach.

3.1. Benchmark model

We adopt a real options framework, where project cashflows serve as the underlying variable for evaluating investment decisions. Within a decentralized corporate structure, we focus on the timing of investments for a single project. The decision-making authority concerning investment timing is vested in the manager (agent) by the owner (principal).[3] The project's cashflow is modeled as a geometric Brownian motion (GBM) process and denoted by $X(t)$. Both the owner and manager observe $X(t)$, which drives the investment timing strategy. The dynamics of $X(t)$ follow the stochastic differential equation:

$$\mathrm{d}X(t) = \alpha X(t)\mathrm{d}t + \sigma X(t)\mathrm{d}B(t), \quad t > 0,$$
$$X(0) = x \tag{1}$$

Here, $B(t)$ is a standard Brownian motion within a filtered probability space $(\Omega, \mathcal{F}, \mathbb{P}, \{\mathcal{F}_t\})$, with $\mathcal{F}_t$ encapsulating the available information at any given time t, and $\mathbb{P}$ representing the physical probability measure. The stochastic process is initiated with $X(0) = x$, where $\alpha \geq 0$ denotes the drift coefficient and $\sigma > 0$ the volatility factor, with x being the initial value.

To quantitatively assess the risk associated with unsustainable projects, we introduce a Poisson intensity parameter $\lambda(> 0)$ to represent the ESG risk.[4] The cash flow $X(t)$ falls 0 at the Poisson jump time with a rate parameter λ. For unsustainable projects, this parameter λ is assumed to be higher due to elevated ESG risks, such as labor exploitation and environmental degradation. These risks increase the likelihood of indefinite project suspension, implying that λ reflects the probability of the project's cash flows ceasing at an unforeseen moment due to these ESG concerns. On the contrary, sustainable projects, associated with lower ESG risks, exhibit a lower λ, indicating a higher degree of continuity in their cash flows. Therefore, λ serves as a critical indicator of the ESG risk profile, differentiating between sustainable and unsustainable ventures in terms of their expected project lifespan and financial viability. It should be noted that we do not consider the case where $\lambda = 0$, as this would render the occurrence of $X(t)$ falling 0 a signal; that is, a cash flow disruption would reveal that the project is unsustainable, thereby contradicting the assumption of asymmetric information.

We delineate two divergent paths for each single project under consideration: For a project aligning with ESG standards – a sustainable project – a very low ESG risk is associated. The expected net present value (NPV) of investing in a sustainable project at the initial stage can is calculated as follows:

$$E\left[\int_0^\infty \lambda_1 e^{-\lambda_1 s} \int_0^s e^{-rt} X(t) dt ds\right] = u_1 x,$$

Conversely, for a project imbued with ESG risks – an unsustainable project – presents an expected NPV at the inception of investment:

$$E\left[\int_0^\infty \lambda_2 e^{-\lambda_2 s} \int_0^s e^{-rt} X(t) dt ds\right] = u_2 x$$

where r represents the discount rate, and u_1 and u_2 are defined by $u_1 = (r - \alpha + \lambda_1)^{-1}$ and $u_2 = (r - \alpha + \lambda_2)^{-1}$.

We assume an unsustainable project has a higher ESG risk than a sustainable one, which indicates $\lambda_1 < \lambda_2$. It is evident from these formulations that the expected NPV of a sustainable project surpasses that of an unsustainable one (i.e., $u_1 x > u_2 x$).

In the allocation of projects under the manager's purview, two distinct possibilities arise: the undertaking of a sustainable project, associated with a cost I_1, and an unsustainable project with a cost I_2, where we assume $I_1 > I_2$. Here, I_i $(i \in \{1, 2\})$ represents the investment cost at the time of undertaking the sustainable and unsustainable projects, respectively. The manager, possessing exclusive insights into the project's ESG risk, may be driven by self-interest or momentary opportunism to mislead the owner, claiming to have embarked on the sustainable venture while actually allocating capital to the unsustainable option, which entails higher ESG risks. This misbehavior allows the manager to secretly benefit from cost savings, quantified as $\Delta I = I_1 - I_2 > 0$, which remain undisclosed to the owner. Because of this misrepresentation, the owner's anticipated value is computed as $u_2 x - I_1$. Here, $u_2 x$ signifies the value from the unsustainable project, whereas I_1 is indicative of the higher cost associated with the sustainable project that the owner is led to believe has been funded. The conflict of interest between the manager and the owner, stemming from asymmetric information, will be further examined in the ensuing sections of this paper.

Now we establish a benchmark model without asymmetric information, where the exercise decision is not delegated and the owner possesses accurate information of the true ESG risk and observes the real investment cost denoted by I. In this context, with a specified $I = I_i$ (where $i = 1, 2$), the owner faces an optimal stopping problem. Specifically, the owner must decide the optimal timing to invest in the project to maximize the NPV. This problem is formulated as follows:

$$W(x; I_i) = \sup_{\tau_i \in \mathcal{T}} \mathbb{E}\left[e^{-r\tau_i}(u_i X(\tau_i) - I_i)\right] \tag{2}$$

where $\mathcal{T}$ denotes the set of all $\mathcal{F}_t$ -measurable stopping times, the stopping time τ_i is the moment at which the owner decides to invest the project, and r is a constant risk-free rate satisfying $r > \alpha$. This study presupposes that the initial asset value x is sufficiently low, necessitating a delay until the exercise condition is satisfied.

3.2. Baseline and subsidy model

In ESG investments, information asymmetry arises when managers possess private knowledge about a project's true sustainability risk type – either λ_1 (unsustainable) or λ_2 (sustainable) – whereas owners

[3] In this paper, we use the terms "owner", "investor", and "principal", as well as the terms "manager" and "agent" interchangeably. Here, "owner" refers to the company's shareholders, some of whom may be portfolio managers (investors) with a focus on ESG concerns; "manager" refers to executives (e.g., CEOs) or operational decision-makers actively engaged in firm management.

[4] Many existing studies have investigated ESG risk and demonstrated its significant impact on firm value, highlighting that ESG risk can increase downside risks (e.g., Gillan et al. (2021)). Hong et al. (2023a, 2023b) also incorporate a Poisson intensity parameter to simulate the occurrence of natural disasters. We expand our model to encapsulate the nuances of ESG risks and their significance in shaping corporate strategic imperatives. Building on Nishihara (2024)'s work, we recognize ESG risks through a quantifiable lens, which emphasizes the heightened scrutiny of corporate ESG practices. Contemporary research underscores the risks that high-pollution projects or those involving labor exploitation pose—not only to environmental and social welfare but also to the company's legal standing and operational viability once these risks are disclosed. Elevated ESG risks, as parameterized in the model, signal the potential unsustainability of a project, warranting regulatory intervention and potentially severe legal repercussions.

observe only the realized cash flows $X(t)$. This asymmetry creates a classic principal–agent problem: managers may misreport unsustainable projects as sustainable to capture the cost differential $\Delta I = I_1 - I_2$ as private gain. Such misreporting distorts investment timing and undermines trust, potentially delaying socially desirable ESG investments. To address this, we construct an incentive-auditing contract that penalizes misreporting ($d_i\Gamma$) and rewards truthful disclosure (w_i).[5] Specifically, $w_i \geq 0$ (for $i = 1, 2$) denotes the incentive-compatible transfer awarded to managers for honest reporting under each type of project.

To further ensure the deep implementation of corporate sustainability and social responsibility, we introduce a mechanism encompassing auditing, as proposed in Nishihara and Shibata (2008). If a manager is found to have submitted a false report, they incur a penalty $\Gamma > 0$. The auditing level $d_i \in [0, 1)$ captures the probability that the owner detects such misreporting. This range reflects the realistic limitation that audit mechanisms are not perfectly effective. Consequently, if the manager chooses to misreport, the expected penalty is given by $d_i\Gamma$. Although higher auditing intensity improves information accuracy and protects investment returns, it comes at a cost. We define an increasing and convex auditing cost function $c(d_i)$ with $c(0) = 0$ and $\lim_{d_i \to 1} c(d_i) = +\infty$, reflecting that low audit effort is inexpensive, whereas achieving near-perfect detection is prohibitively costly. It is assumed that $c'(d_i) > 0$ and $c''(d_i) > 0$ for $d_i \in [0, 1)$ to ensure strict convexity. Both the penalty Γ and the cost function $c(d_i)$ are treated as exogenous parameters. This framework allows the owner to balance the benefits of improved compliance through auditing and penalties with the rising costs of implementation, ultimately supporting an incentive-compatible solution under information asymmetry.

The decision process unfolds as follows. At time $t = 0$, the owner offers a contract specifying audit penalties and incentive payments. Immediately after ($t = 0^+$), the manager privately observes the true type of the project and reports it to the owner. Based on this report, the manager sets an investment trigger threshold, and decides when to invest accordingly. To verify the report, the owner audits the manager; if no misreporting is detected, the manager receives the incentive for truthful disclosure. If the reported project is identified as sustainable, the owner additionally receives a government-provided subsidy.[6] We assume a positive subsidy amount $s > 0$, which is granted exclusively for verifiably sustainable investments.[7]

4. Model solutions

In this section, we derive and elucidate the solutions of the aforementioned model. Furthermore, we show several propositions that stem from our analysis.

4.1. Benchmark solution

Using the standard method by Dixit and Pindyck (1994) we can derive the value function $W(x; I_i)$ and the corresponding optimal stopping time τ_i^* of problem (2) for $I = I_i$ as follows:

$$W(x; I_i) = \left(\frac{x}{X_i^*}\right)^{\beta} (u_i X_i^* - I_i), \tag{3}$$

$$\tau_i^* = \inf\{t \geq 0 | X(t) \geq X_i^*\},$$

$$X_i^* = \frac{\beta I_i}{(\beta - 1)u_i},$$

where, β is defined by $\beta = 0.5 - \alpha/\sigma^2 + \sqrt{\left(\alpha/\sigma^2 - 0.5\right)^2 + 2r/\sigma^2}$, $(\beta > 1)$. The threshold X_i^* represents the optimal investment trigger for the owner who observes the value I_i at the initial time 0. Let q denote the probability assigned to a sustainable project[8] . Thus, the ex ante value of the owner's option in the first-best no-agency setting (denoted $V^*(x)$) becomes

$$\begin{aligned} V^*(x) &= qW(x; I_1) + (1 - q)W(x; I_2) \\ &= q\left(\frac{x}{X_1^*}\right)^{\beta} (u_1 X_1^* - I_1) + (1 - q)\left(\frac{x}{X_2^*}\right)^{\beta} (u_2 X_2^* - I_2) \end{aligned} \tag{4}$$

4.2. Baseline solution

In this scenario, the investment option is retained by the owner who delegates the decision-making authority to the manager. At the initial stage, time 0, the owner commits through a contract to compensate the manager upon the exercise of the option, with the assumption that renegotiation is infeasible. It is important to note that the manager might be tempted to deceive the owner for a personal gain of ΔI. This possibility necessitates the owner to establish a mechanism that deters such deceptive actions. By incorporating incentives w_i and auditing costs $c(d_i)$ at investment threshold X_i, this framework (drawing from Grenadier and Wang (2005) and Nishihara and Shibata (2008)) lays the groundwork for developing the following optimization problem:

$$\begin{aligned} \max_{w_i, X_i, d_i} \; & q\left(\left(\frac{x}{X_1}\right)^{\beta} (u_1 X_1 - I_1 - w_1 - c(d_1))\right) \\ & + (1 - q)\left(\left(\frac{x}{X_2}\right)^{\beta} (u_2 X_2 - I_2 - w_2 - c(d_2))\right) \end{aligned} \tag{5}$$

$$\begin{aligned} \text{subject to} \quad & q\left(\frac{x}{X_1}\right)^{\beta} w_1 + (1 - q)\left(\frac{x}{X_2}\right)^{\beta} w_2 \geq 0 \\ & w_i \geq 0; \quad d_i \geq 0 \\ & \left(\frac{x}{X_1}\right)^{\beta} w_1 - \left(\frac{x}{X_2}\right)^{\beta} \left(w_2 - \Delta I - d_2\Gamma\right) \geq 0 \end{aligned} \tag{6}$$

[5] The design of incentives often plays a crucial role in corporate finance to alleviate the agency conflicts between managers and owners (shareholders) (e.g., Grenadier and Wang (2005)). The incentives are strategically significant as they mitigate agency conflicts between managers and shareholders. An optimal contract is designed to induce the manager to truthfully reveal private information and exert effort in investment decisions.

[6] The modeling of government subsidies for sustainable projects is grounded in real-world practices. Many countries implement subsidy policies – such as investment tax credits or direct grants – to support green bonds and ESG-oriented investments (e.g., Azhgaliyeva et al. (2020), Chen and Zhao (2021), Kosztowniak (2023) and Tu and Rasoulinezhad (2021)). Because the World Bank's green subsidies database indicates an increasing trend in the governmental use of green subsidies to catalyze green technologies and transitions, governments in Europe (e.g., Germany, France), ASEAN, and China actively issue subsidies or tax benefits to promote renewable energy and energy-efficient infrastructure. Empirical studies also confirm the positive impact of such subsidies on ESG performance and investment behavior (e.g., Peng and Sun (2024), Song and Dong (2024), Wang et al. (2024) and Zhang et al. (2023)). In our model, We establish that only sustainable projects qualify for this subsidy, which may alter project selection and management decisions.

[7] Other forms of public support, such as tax reductions, yield equivalent results under our model specification. Thus, we focus on direct subsidies without loss of generality.

[8] In our model, we assume the probability q of encountering an ESG-compliant project to be exogenously given and independent of managerial agency. This simplifies the analysis by isolating the effects of asymmetric information and incentive design, consistent with prior studies on delegated investment under hidden information (e.g., Nishihara and Shibata (2008) and Zhang and Yang (2024)). Although managerial effort could endogenously affect project types (as in Grenadier and Wang (2005)), our results – such as the misreporting-driven incentive paradox and the non-monotonic welfare effects of transparency – are robust to this assumption. See Section 5.4 for further discussion.

$$\left(\frac{x}{X_2}\right)^{\beta} w_2 - \left(\frac{x}{X_1}\right)^{\beta} (w_1 + \Delta I - d_1 \Gamma) \geq 0$$

The owner specifies threshold X_1 (respectively, X_2), provides incentive w_1 (respectively, w_2), and chooses audit level d_1 (respectively, d_2) for the manager who reports the sustainable (respectively, unsustainable) project. The term $\left(\frac{x}{X_i}\right)^{\beta}$ represents the expected discounted value of \$1 contingent on $X(t)$ hitting the threshold X_i, where $X_i > x$ is presumed. Within the constraints of inequalities (6), the first and second inequalities respectively represent the ex ante participation constraint and the ex post limited-liability constraints. The latter two inequalities represent the ex post incentive-compatibility constraints. The incentive-compatibility constraints ensure the scenario where the manager, driven by the prospect of a positive payoff, will provide the owner with an accurate and credible report. Specifically, when the manager observes and realizes that the project attribute is sustainable, which is $I_i = I_1$ (respectively, $I_i = I_2$ with unsustainable one), he will report honestly to the owner. The expected payoff for doing so, $\left(\frac{x}{X_1}\right)^{\beta} w_1$ (respectively, $\left(\frac{x}{X_2}\right)^{\beta} w_2$), is higher than the expected payoff from providing false information, $\left(\frac{x}{X_2}\right)^{\beta} (w_2 - \Delta I - d_2 \Gamma)$ (respectively, $\left(\frac{x}{X_1}\right)^{\beta} (w_1 + \Delta I - d_1 \Gamma)$). By solving the optimization problem above, we obtain the following proposition. Proof is provided in Appendix A.1.

Proposition 1. *The optimal contract* $\{(X_i, w_i, d_i) \mid i = 1, 2\}$ *in the baseline setting is given as follows:*
Case A: $\Gamma \leq qc'(0)/(1-q)$ *(incentive only region).*

$$(X_1, w_1, d_1) = (\frac{\beta}{(\beta-1)u_1}(\frac{1-q}{q}\Delta I + I_1), 0, 0)$$

$$(X_2, w_2, d_2) = (X_2^*, (\frac{X_2^*}{X_1})^{\beta} \Delta I, 0)$$

Case B: $qc'(0)/(1-q) < \Gamma \leq \max\{\Delta I, qc'(\Delta I/\Gamma)/(1-q)\}$ *(joint incentive and auditing region).*

$$(X_1, w_1, d_1) = (\frac{\beta}{(\beta-1)u_1}(I_1 + c(d_1) + \frac{1-q}{q}(\Delta I - d_1 \Gamma)), 0, c'^{-1}(\frac{(1-q)\Gamma}{q}))$$

$$(X_2, w_2, d_2) = (X_2^*, (\frac{X_2^*}{X_1})^{\beta}(\Delta I - d_1 \Gamma), 0)$$

Case C: $\Gamma > \max\{\Delta I, qc'(\Delta I/\Gamma)/(1-q)\}$ *(auditing only region).*

$$(X_1, w_1, d_1) = (\frac{\beta}{(\beta-1)u_1}(I_1 + c(d_1)), 0, \frac{\Delta I}{\Gamma})$$

$$(X_2, w_2, d_2) = (X_2^*, 0, 0)$$

Table 1 provides a simplified summary of value signs for each component in the optimal contract characterized by Proposition 1. We identify three main cases based on the effectiveness of incentives and auditing: Case A (relying solely on incentives), Case B (combining incentives and auditing), and Case C (relying solely on auditing). Depending on the situation, the owner may rely more on incentives only, a combination of both incentives and auditing, or auditing only to ensure truthful reporting by the manager. In **Case A**, where auditing is entirely ineffective, the owner relies solely on incentive payments, fully surrendering the information rent to the manager and dispensing with auditing altogether. In **Case B**, the owner adopts a mixed approach, using both incentives and auditing in response to intermediate levels of audit effectiveness and penalty severity, balancing audit costs and enforcement strength. In **Case C**, where penalties are severe and auditing is relatively inexpensive, the owner relies exclusively on auditing and forgoes incentive payments, leveraging the threat of punishment to enforce truthful reporting.

Moreover, we can observe that only managers of unsustainable projects can receive a reward ($w_2 \geq 0$) and without facing auditing ($d_2 = 0$), whereas managers of sustainable projects have no such opportunities ($w_1 = 0$ always hold) with a probable auditing level ($d_2 \geq 0$), which seems to not align with the principles of ESG. The intuition behind this is rooted in our assumption that the cost of sustainable projects is higher than the cost of unsustainable projects ($I_1 > I_2$), with the cost difference creating an incentive for managers to issue false reports. To achieve a positive profit, managers are only motivated to disguise unsustainable projects as sustainable ones; the reverse cannot yield any financial benefit. Consequently, the owner is not motivated to audit a manager who has already reported the project as sustainable, as there is no plausible motivation for the manager to mislead in such a situation.

Table 1
Baseline model optimal contract components across different cases. This table summarizes the numerical components from Proposition 1. It illustrates the investment thresholds X_1 and X_2 compared to the benchmark thresholds X_1^* and X_2^*, as well as the effectiveness of the incentive-auditing contract, as indicated by the signs of incentives w_i and auditing levels d_i. The symbol "+" denotes a positive value rather than "0".

	X_1	X_2	w_1	w_2	d_1	d_2
Case A: (incentive only)	Higher than X_1^*	X_2^*	0	+	0	0
Case B: (joint)	Higher than X_1^*	X_2^*	0	+	+	0
Case C: (auditing only)	Higher than X_1^*	X_2^*	0	0	+	0

Table 2
Optimal contract components with subsidies across different cases. This table summarizes the numerical components from Propositions 2 and 3. It illustrates the investment thresholds X_1 and X_2 compared to the benchmark thresholds X_1^* and X_2^*, as well as the effectiveness of the incentive-auditing contract, as indicated by the signs of incentives w_i and auditing levels d_i. The symbol "+" denotes a positive value rather than "0", and the symbol "++" indicates a value that is larger than the positive value presented in Table 1. s^* denotes the optimal subsidy from the Proposition 3.

	X_1	X_2	w_1	w_2	d_1	d_2	s^*
Case A: (incentive only)	X_1^*	X_2^*	0	++	0	0	0
Case B: (joint)	Higher than X_1^*	X_2^*	0	++	++	0	+
Case C: (auditing only)	Higher than X_1^*	X_2^*	0	0	+	0	+

To conduct a more in-depth analysis of the decision-making processes of owners and managers, along with the potential social losses incurred, an examination of their impact on social welfare is essential. We consider that a social welfare function, denoted as $SW(x)$, is defined as the aggregate value of all stakeholders, encompassing both the owner's and manager's expected payoffs. This function serves to evaluate the social welfare implications emerging from principal–agent issues, primarily driven by information asymmetry and the complexities inherent in the design of incentive mechanisms.

Let $\pi_o(x)$ and $\pi_m(x)$ denote the owner's and manager's ex ante option values. From Proposition 1, they are derived as follows:

$$\pi_o(x) = q\left(\left(\frac{x}{X_1}\right)^{\beta}(u_1 X_1 - I_1 - c(d_1))\right) + (1-q)\left(\left(\frac{x}{X_2^*}\right)^{\beta}(u_2 X_2^* - I_2 - w_2)\right)$$

$$\pi_m(x) = (1-q)\left(\frac{x}{X_2^*}\right)^{\beta} w_2$$

The social welfare function $SW(x)$ is composed as follows:

$$SW(x) = \pi_o(x) + \pi_m(x) = q\left(\left(\frac{x}{X_1}\right)^{\beta}(u_1 X_1 - I_1 - c(d_1))\right)$$

$$+ (1-q)\left(\left(\frac{x}{X_2^*}\right)^{\beta}(u_2X_2^* - I_2)\right) \quad (7)$$

$\pi_o(x)$ represents the owner's expected payoff, which hinges on investment timing decisions regarding sustainable and unsustainable projects. The payoff is calculated by discounting the investment returns, considering the associated investment costs, bonus incentives, and auditing costs. $\pi_m(x)$ signifies the manager's expected payoff, which is derived from the bonus incentive w_2 at the unsustainable investment threshold X_2. In the formulas presented, q represents the probability that a project is sustainable, whereas $(1-q)$ indicates the probability that a project is unsustainable.

4.3. Subsidy solution

Now consider the introduction of a subsidy policy implemented by the government to encourage sustainable investment. For simplicity, we define this as a direct subsidy provided exclusively for investments in sustainable projects. Let s denote the subsidy. For the given s, the owner designs the optimal contract as in the baseline problem in Section 4.2. The optimization problem is reduced to the following:

$$\max_{w_i,X_i,d_i} q\left(\left(\frac{x}{X_1}\right)^{\beta}(u_1X_1 - I_1 + s - w_1 - c(d_1))\right)$$
$$+ (1-q)\left(\left(\frac{x}{X_2}\right)^{\beta}(u_2X_2 - I_2 - w_2 - c(d_2))\right)$$

subject to (6)

By solving the optimization problem above, we have the following proposition. Proof is analogous to that presented in Appendix A.1; hence, it is omitted.

Proposition 2. *The optimal contract $\{(X_i, w_i, d_i) \mid i = 1,2\}$ in the setting with subsidy s is given as follows:*
Case A: *$\Gamma \le qc'(0)/(1-q)$ (incentive only region).*

$$(X_1, w_1, d_1) = (\frac{\beta}{(\beta-1)u_1}(\frac{1-q}{q}\Delta I + I_1 - s), 0, 0)$$

$$(X_2, w_2, d_2) = (X_2^*, (\frac{X_2^*}{X_1})^{\beta}\Delta I, 0)$$

Case B: *$qc'(0)/(1-q) < \Gamma \le \max\{\Delta I, qc'(\Delta I/\Gamma)/(1-q)\}$ (joint incentive and auditing region).*

$$(X_1, w_1, d_1) = (\frac{\beta}{(\beta-1)u_1}(I_1 - s + c(d_1) + \frac{1-q}{q}(\Delta I - d_1\Gamma)), 0, c'^{-1}(\frac{(1-q)\Gamma}{q}))$$

$$(X_2, w_2, d_2) = (X_2^*, (\frac{X_2^*}{X_1})^{\beta}(\Delta I - d_1\Gamma), 0)$$

Case C: *$\Gamma > \max\{\Delta I, qc'(\Delta I/\Gamma)/(1-q)\}$ (auditing only region).*

$$(X_1, w_1, d_1) = (\frac{\beta}{(\beta-1)u_1}(I_1 - s + c(d_1)), 0, \frac{\Delta I}{\Gamma})$$

$$(X_2, w_2, d_2) = (X_2^*, 0, 0)$$

Table 2 summarizes the value signs for key components of the optimal contracts under subsidy conditions, across Cases A, B, and C. It displays how the investment thresholds, incentives, auditing levels, and subsidy values change in each regime, compared to the baseline results presented in Table 1. The solution in Proposition 2 indicates that the introduction of the subsidy does not affect the delineation among the different cases. Furthermore, we observe that X_1 diminishes due to the introduction of the subsidy, indicating that the sustainable investment occurs earlier. This shift is a direct consequence of the subsidy and is indeed consistent with the government's intent to encourage ESG investing. As in Section 4.2, we examine the ex ante option value functions:

$$\pi_o(x) = q\left(\frac{x}{X_1}\right)^{\beta}(u_1X_1 - I_1 + s - c(d_1))$$
$$+ (1-q)\left(\frac{x}{X_2^*}\right)^{\beta}(u_2X_2^* - I_2 - w_2)$$
$$\pi_m(x) = (1-q)\left(\frac{x}{X_2^*}\right)^{\beta} w_2$$

To better explore the impact of subsidies on society within this model, we define the social welfare function with given subsidy s as the payoff of the owner and manager minus the government's expenditure. The social welfare function is calculated as follows:

$$SW(x) = \pi_o(x) + \pi_m(x) - q\left(\frac{x}{X_1}\right)^{\beta} s$$
$$= q\left(\frac{x}{X_1}\right)^{\beta}(u_1X_1 - I_1 - c(d_1)) + (1-q)\left(\frac{x}{X_2^*}\right)^{\beta}(u_2X_2^* - I_2)$$

It can be observed that because subsidies are funded by the government, and government revenue is derived from corporate earnings, the portion of the subsidy will ultimately be offset as it translates into an increase in the owner's surplus. Consequently, the social welfare function with subsidies is formally equivalent to (7), with the distinction that X_1 differs.

The next proposition identifies the value of s that maximizes $SW(x)$ in each case. Proof is presented in Appendix A.2.

Proposition 3. *The optimal subsidy s to maximize social welfare is given as follows:*
Case A: *$\Gamma \le qc'(0)/(1-q)$ (incentive only region).*

$$s^* = \frac{1-q}{q}\Delta I.$$

Case B: *$qc'(0)/(1-q) < \Gamma \le \max\{\Delta I, qc'(\Delta I/\Gamma)/(1-q)\}$ (joint incentive and auditing region).*

$$s^* = \frac{1-q}{q}(\Delta I - d_1\Gamma).$$

Case C: *$\Gamma > \max\{\Delta I, qc'(\Delta I/\Gamma)/(1-q)\}$ (auditing only region).*

$$s^* = 0.$$

In Case A, where incentives are the sole mechanism, the optimal subsidy s^* offsets the delay caused by asymmetric information, resulting $X_1 = X_1^*$ and $SW(x) = V^*(x)$, thus achieving the first-best social welfare. Conversely, in Case C, which relies only on auditing, the subsidy policy is ineffective, leaving the social welfare unchanged from the baseline social welfare.

5. Numerical analysis and discussions

5.1. Baseline results

Having derived the mathematical results of our optimization problem, we now elucidate their implications through numerical analysis. The baseline parameters are outlined in Table 3. The values of α, σ, and r align with standard assumptions in dynamic corporate finance literature, reflecting a typical S&P 500 firm.[9]

To quantitatively assess the risk associated with unsustainable projects, we introduce a Poisson intensity parameter $\lambda(> 0)$, representing the ESG risk profile of such ventures.[10] We set $\lambda_2 = 0.1$ to represent the ESG risk of the unsustainable project and $\lambda_1 = 0.05$ for

[9] See foundational works in Arnold (2014) and Morellec (2001), and contemporary extensions in Nishihara (2024).

Table 3
Baseline parameter values. α represents the drift rate; σ denotes volatility; r is the discount rate; q indicates the sustainability probability; x is the initial state variable; I_1 and I_2 correspond to the investment costs for sustainable and unsustainable projects, respectively; λ_1 and λ_2 represent the ESG risk intensities for the sustainable and unsustainable projects, respectively; Γ is the social cost multiplier; and $c(d)$ represents a convex damage cost function with information asymmetry parameter k.

α	σ	r	q	x	I_1	I_2	λ_1	λ_2	Γ	$c(d)$
0.01	0.2	0.05	0.5	0.1	1.5	1	0.05	0.1	1	$\frac{kd}{1-d}$

the sustainable project. For simplicity, we set $q = 0.5$ (50% probability of project sustainability), with sensitivity analysis to q in Section 5.4. The baseline case assumes $x = X(0) = 0.1$, which is sufficiently low to preclude immediate investment. Cost parameters $I_1 = 1.5$, $I_2 = 2$, and $\Gamma = 2\Delta I = 1$ ensure comparability between project valuations.

We have established a cost function for auditing $c(d)$ in Table 3, where the parameter k within the cost function represents the level of information asymmetry.[11] In our baseline model, it reflects the extent of the cost incurred when implementing auditing measures. More specifically, a lower value of k indicates a smaller auditing cost and a higher degree of corporate transparency. That is, in a transparent corporation, a manager's false report is more likely to be detected, incurring greater risk and cost for the manager. Conversely, a higher value of k corresponds to a larger auditing cost, suggesting a lower level of transparency. This lower transparency makes it more difficult to uncover a manager's false report, thereby providing greater incentives for the manager to engage in deceptive reporting for personal gain. Based on Nishihara and Shibata (2008), for simplicity, we adopt the functional form $c(d) = kd/(1-d)$ (as specified in Table 3), as it represents the simplest function satisfying the required conditions. In terms of parameter k, we can categorize the regions of three cases as follows:

Case C: $k < (1-q)\Gamma(\Delta I/\Gamma - 1)^2/q = 0.25$ (auditing only region).
Case B: $0.25 = (1-q)\Gamma(\Delta I/\Gamma - 1)^2/q \le k < \Gamma(1-q)/q = 1$ (joint incentive and auditing region).
Case A: $1 = \Gamma(1-q)/q \le k$ (incentive only region).

To support our numerical findings, we also derive analytical comparative statics with respect to the transparency parameter k. Specifically, we show that in Case A, both $\partial X_1/\partial k$ and $\partial X_1^*/\partial k$ are equal to zero; in Case C, both derivatives are negative, indicating that higher transparency promotes earlier investment. In Case B, however, the sign of the derivatives is ambiguous and depends on parameter values.

In this framework, we have generated Fig. 2. The dashed line represents the baseline scenario with no subsidy, whereas the solid line indicates the dynamics following the implementation of the optimal subsidy.

In Panel (a) of Fig. 2, we observe that higher transparency (lower information asymmetry) accelerates investment in sustainable projects, indicating the benefits of transparency in ESG initiatives. Notably, after the introduction of government subsidies, X_1 exhibits a significant change in behavior as it no longer varies monotonically with k. Instead, it transitions from an increasing to a decreasing pattern at relatively high information asymmetry levels (Cases A and B). This intriguing outcome suggests that subsidies expedite sustainable project investments, thereby enhancing the ESG investment environment when transparency is sufficiently low. In Panel (b), it is evident that higher information asymmetry increases the incentives received by managers, serving as a rent for their private information costs. Following the introduction of subsidies, a portion of these subsidies is also allocated to managers. Panel (c) notes that at low information asymmetry levels (Case C), the owner's actual auditing cost budget escalates with increasing information asymmetry. In Case B, the rising cost of auditing due to higher information asymmetry outpaces the benefits derived from successful audits, leading the owner to gradually reduce the auditing budget, potentially culminating in the complete abandonment of auditing efforts (Case A). The introduction of subsidies is observed to replenish the owner's auditing budget, allowing for an increased allocation of auditing costs in Case B compared to the scenario without subsidies.

In summary, an increase in the information asymmetry k of corporate governance tends to delay sustainable investment. Concurrently, owners are compelled to offer more substantial incentives to managers to ensure the authenticity of the information provided. With fluctuations in k, there exists a maximum threshold for the cost of auditing. Specifically, in a corporate environment with relatively low k, owners initiate audits because the cost is sufficiently low and thus serves as an effective deterrent towards managers. In contrast, as k rises, the increased cost of auditing can deter owners from participating in the auditing process.

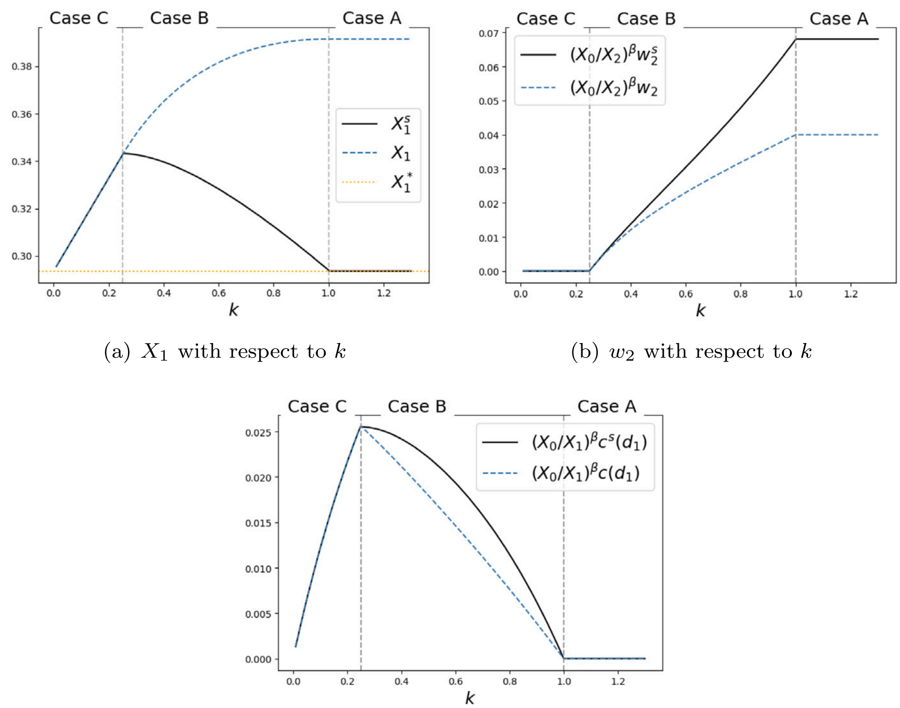
After the introduction of government subsidies, they are allocated to the owner's option value and the incentives given to the manager, increasing their benefits. It is also confirmed that X_1, the trigger value for sustainable investment, has decreased, which means that the timing of sustainable investment has been accelerated. This is indeed a positive development for ESG, aligning with the ESG principle. However, an intriguing aspect of the subsidy policy is that, in environments characterized by relatively high information asymmetry (Cases A and B), the trigger value X_1 experiences a reversal in the baseline result with no subsidy. Indeed, as k increases, X_1 decrease in Cases B and reaches the lowest level in Case A. The lowest level is equal to the first-best level X_1^*, which is also achieved by Case C with $k = 0$. While the subsidy policy can significantly promote ESG investments and reduce the delays in investment timing for sustainable projects, especially in low corporate transparency, it may also inadvertently encourage a governance environment with higher information asymmetry. This could potentially detract from the motivation for firms to enhance their corporate transparency, thereby impacting the Governance aspect of ESG in a contentious manner. This finding diverges from those of Zhang et al. (2023), who concluded that corporate transparency serves as a positive mediator in the relationship between ESG performance and government subsidies.

5.2. Option value and social welfare results

The influence of corporations on social welfare is garnering increasing attention (Zhang & Yang, 2024). Now, we delve into the expected option values for both the owner and the manager, as well as their cumulative contribution to Social Welfare. The aforementioned conclusions encapsulate the potential shifts in social welfare that arise in the context of agency problems. These shifts are primarily the result of information asymmetry and the complexities inherent in the design of incentive mechanisms. A thorough investigation into social welfare provides a more sophisticated understanding of the impact that diverse incentive mechanisms and audit strategies can have on the broader societal well-being. Such an analysis serves as a critical tool in guiding the formulation of optimal contractual agreements and the crafting of effective regulatory policies. Utilizing the baseline parameter values, we have generated Fig. 3. This visualization aids in illustrating the intricate dynamics between the parties involved and the societal welfare at large.

[10] Following Adkins and Paxson (2016) and Boomsma and Linnerud (2015), who model renewable energy policy uncertainty as a Poisson jump process with a hazard rate of 0.1, we set $\lambda_2 = 0.1$ to represent the ESG risk of the unsustainable project and $\lambda_1 = 0.05$ for the sustainable project. This implies the expected lifetime of the unsustainable project is $1/\lambda_2 = 10$ years, whereas the sustainable project has cash flows lasting $1/\lambda_1 = 20$ years.

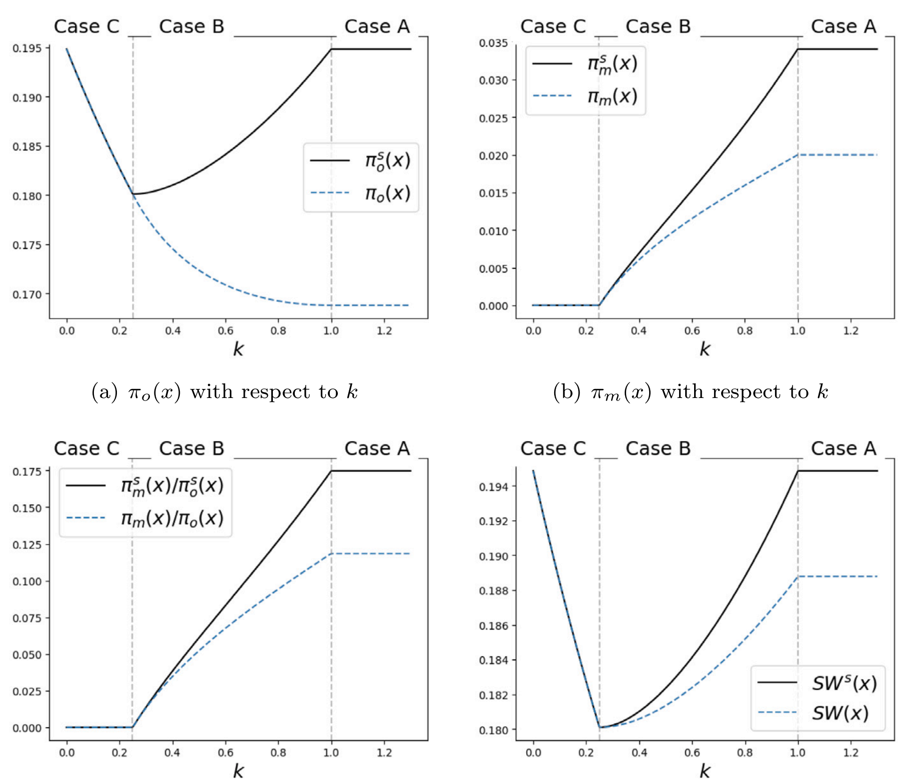
[11] The level of information asymmetry can be regarded as a proxy for corporate opacity, reflecting the extent to which both financial and nonfinancial data are disclosed.



(a) X_1 with respect to k (b) w_2 with respect to k

(c) $c(d_1)$ with respect to k

Fig. 2. Investment threshold X_1, incentive w_2, and auditing cost $c(d_1)$ as functions of the information asymmetry level k. Subscripts 1 and 2 denote the sustainable and unsustainable projects, respectively. The investment thresholds X_1^*, X_1, and X^s represent the benchmark solution, baseline solution, and subsidy solution for sustainable projects, respectively. The dotted, dashed, and solid lines correspond to the benchmark, baseline, and subsidy solutions. The parameter values are set as in Table 3.



(a) $\pi_o(x)$ with respect to k (b) $\pi_m(x)$ with respect to k

(c) π ratio with respect to k (d) $SW(x)$ with respect to k

Fig. 3. Owners' value $\pi_o(x)$, Managers' value $\pi_m(x)$, π ratio, and social welfare $SW(x)$ as functions of the information asymmetry level k. The dashed and solid lines correspond to the baseline, and subsidy solutions. The parameter values are set as in Table 3.

Based on Panel (a) of Fig. 3, we observe that the option value for the owner decreases as the information asymmetry k increases, indicating that opaque governance is detrimental to the owner. Interestingly, the introduction of a subsidy alters the monotonic relationship between π_o and k. With the subsidy, starting from Case B, π_o increases with k until it reaches parity with its value at $k = 0$ when $k \geq 1$ (Case A). This suggests that the subsidy can offset the losses in sustainability caused by information asymmetry due to opaque corporate governance. This result also raises a concern about the potential for owners' moral hazard in corporate governance, as owners of firms with poor governance transparency might unfairly benefit.

In Panel (b), we see that as k increases, the option value for the manager π_m also increases. This is particularly evident in Case B, where the increase is monotonic, reaching a lowest value in Case C and a highest value in Case A. The introduction of the subsidy accelerates this upward trend, especially in Case A, resulting in a higher value than before. This implies that the subsidy also benefits the manager. Panel (c) shows the ratio of the option values between the owner and the manager. This pattern closely resembles that of π_m in panel (b) of Fig. 3. The introduction of the subsidy increases the proportion of the manager's option value. However, a critical issue with the subsidy policy is that it benefits only the managers of unsustainable projects, which contradicts the original intent of the subsidy policy.

Furthermore, as depicted in Panel (d), an interesting observation is that corporate governance and social welfare do not exhibit a simple monotonic relationship. In Case C, characterized by low information asymmetry, social welfare decreases as information asymmetry increases. However, in Case B, this relationship reverses, and social welfare increases with increasing information asymmetry until it stabilizes in Case A. This intriguing result highlights the significant impact of corporate governance on social welfare. A medium level of transparency results in the lowest social welfare, whereas both very low and very high information asymmetry levels improve it. More intriguingly, the implementation of the subsidy raises social welfare in the high information asymmetry region, aligning social welfare in Case A with that in Case C with $k = 0$. This finding suggests that subsidy policies are effective in enhancing social welfare, particularly within the context of corporate governance that is relatively opaque.

5.3. Cash flow volatility

In real options analysis, examining the comparative statics with respect to volatility σ is essential, as σ influences decision-making through the option channel rather than the traditional NPV channel. Fig. 4 illustrates the behaviors of X_1, w_2, $c(d_1)$, $\pi_o(x)$, $\pi_m(x)$, the profit ratio π ratio, and social welfare $SW(x)$ across a range of volatility values, from $\sigma = 0.1$ to 0.5, under a fixed information asymmetry level $k = 0.5$. The dotted, dashed, and solid lines represent the benchmark, baseline, and subsidy solutions, respectively.

We observe that X_1, $\pi_o(x)$, and $SW(x)$ increase monotonically with rising σ, which aligns with standard real options theory: higher uncertainty delays investment timing and increases the option value. Interestingly, however, the variables w_2, $c(d_1)$, and $\pi_m(x)$ exhibit an inverted U shape with respect to σ, reaching a peak at an intermediate level of volatility. This non-monotonic pattern emerges because σ influences the value of the parameter β, which in turn affects the equilibrium outcomes of the contract. Excessively high or low levels of uncertainty reduce the effectiveness of the contract – both auditing costs and incentive payments decrease – resulting in reduced managerial benefits due to diminished incentives. As shown in (d) and (f), owners benefit more from environments with higher volatility, reflecting their ability to capitalize on the enhanced option value.

5.4. Probability of drawing a sustainable project

In ESG investing, the likelihood that managers are assigned to sustainable or unsustainable projects can be influenced by a variety of factors. These include subjective factors such as active investment choices, investor preferences, and corporate policies, as well as external factors such as social environment, cultural atmosphere, and regulatory environment. The existing literature on this topic is currently limited. In this subsection, we analyze the probability q of a manager drawing a sustainable project as the independent variable. We can also categorize the cases based on variations in q:

Case A: $q \geq \Gamma/(k + \Gamma) = 0.66$ (incentive only region).

Case B: $0.33 = 1 - k/(k + \Gamma(\Delta I/\Gamma - 1)^2) \leq q < \Gamma/(k + \Gamma) = 0.66$ (joint incentive and auditing region).

Case C: $q < 1 - k/(k + \Gamma(\Delta I/\Gamma - 1)^2) = 0.33$ (auditing only region).

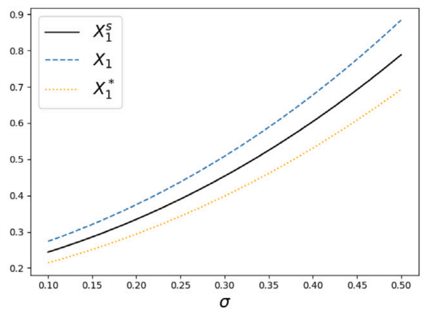
Based on the optimal contracts in Propositions 1 and 2, an increase in the probability q of drawing a sustainable project leads to a decrease in X_1, which means accelerating the investment timing for sustainable projects and thereby increasing the value of incentives within the contract. Additionally, as q increases, it reduces the optimal auditing level in Case B, resulting in lower $c(d_1)$ and diminished risk for the owner. Consequently, in the mass the owner relaxes the auditing intensity as q increases. The comparative static results are presented in Fig. 5, where we set $k = 0.5$.

From Panel (a) of Fig. 5, we observe that as the sustainable project probability q increases, the investment trigger decreases. This indicates that investment occurs more promptly because sustainability is more reliably confirmed, offsetting some effects of information asymmetry. Upon examining Panels (b) and (c), the observations align with the conclusions derived from the optimal contracts mentioned above, indicating that as q increases, the owner is inclined to rely more on incentives and concomitantly reduce the reliance on auditing mechanisms. When q is moderate, Fig. 5 shows that both π_m and π_m/π_o reach their maximum values. In Case B, as q increases, the incentive rises sharply, outweighing the diminishing effect of the prior probability $1-q$ of the unsustainable project, thereby increasing the manager's value. Conversely, in Case A, the increase in incentives with respect to q is gradual (or steady in the presence of a subsidy), and the diminishing effect of the prior probability $1 - q$ of the unsustainable project dominates, causing the manager's value to decrease as q increases. Therefore, the manager's value is maximized when q is moderate.

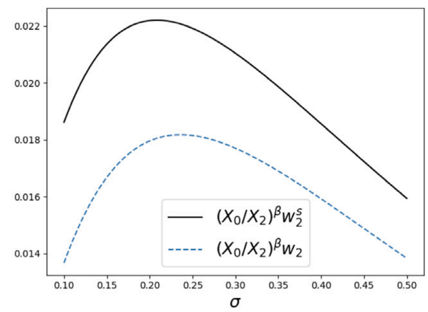
In the moderate level of q, subsidies are most effective in enhancing social welfare $SW(x)$. However, as described in the previous subsection, the manager of an unsustainable project gains most advantage from the subsidy policy, leading to a paradox in corporate governance for sustainability. Considering that q is often moderate in real-life scenarios, we can reasonably infer that subsidies have a certain effect. As a policy implication, we recognize that subsidy policies can accelerate ESG investments, promoting sustainability and increasing social welfare. However, the governance aspect should not be overlooked, especially when q is moderate and corporate opacity is relatively high. The current subsidy benefits managers of unsustainable projects, raising the concern of whether this inadvertently "encourages" unsustainable projects. The core issue stems from information asymmetry. Both incentive contracts and subsidies are essentially compensations for the negative consequences of information asymmetry and opaque corporate governance. In the short term, subsidies indeed promote sustainability. However, in the long term, whether such compensation might condone opaque corporate governance is a question that warrants careful consideration.

5.5. Model-specific mechanisms and robustness considerations

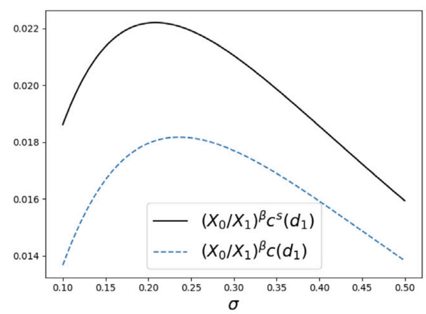
Two counterintuitive results emerge from our model: (1) under the optimal contract, only managers of unsustainable projects receive incentives; and (2) social welfare is higher at both low and high transparency levels, but lowest at intermediate levels. These results arise from structural features of the model and remain robust under the current assumptions.



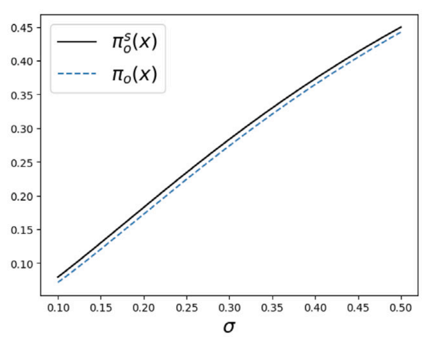
(a) X_1 with respect to σ



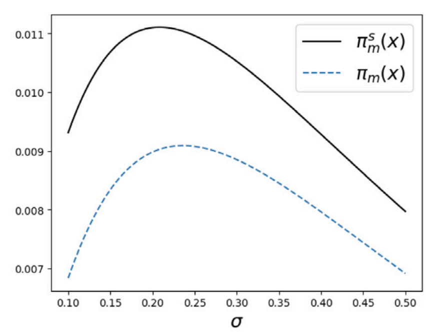
(b) w_2 with respect to σ



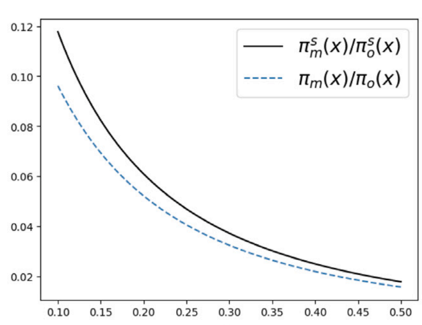
(c) $c(d_1)$ with respect to σ



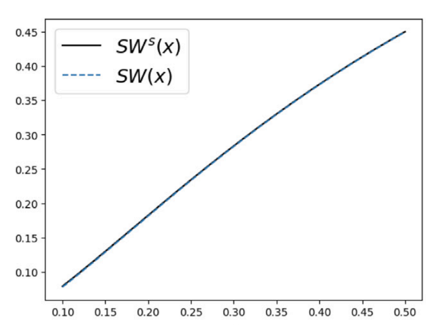
(d) $\pi_o(x)$ with respect to σ



(e) $\pi_m(x)$ with respect to σ



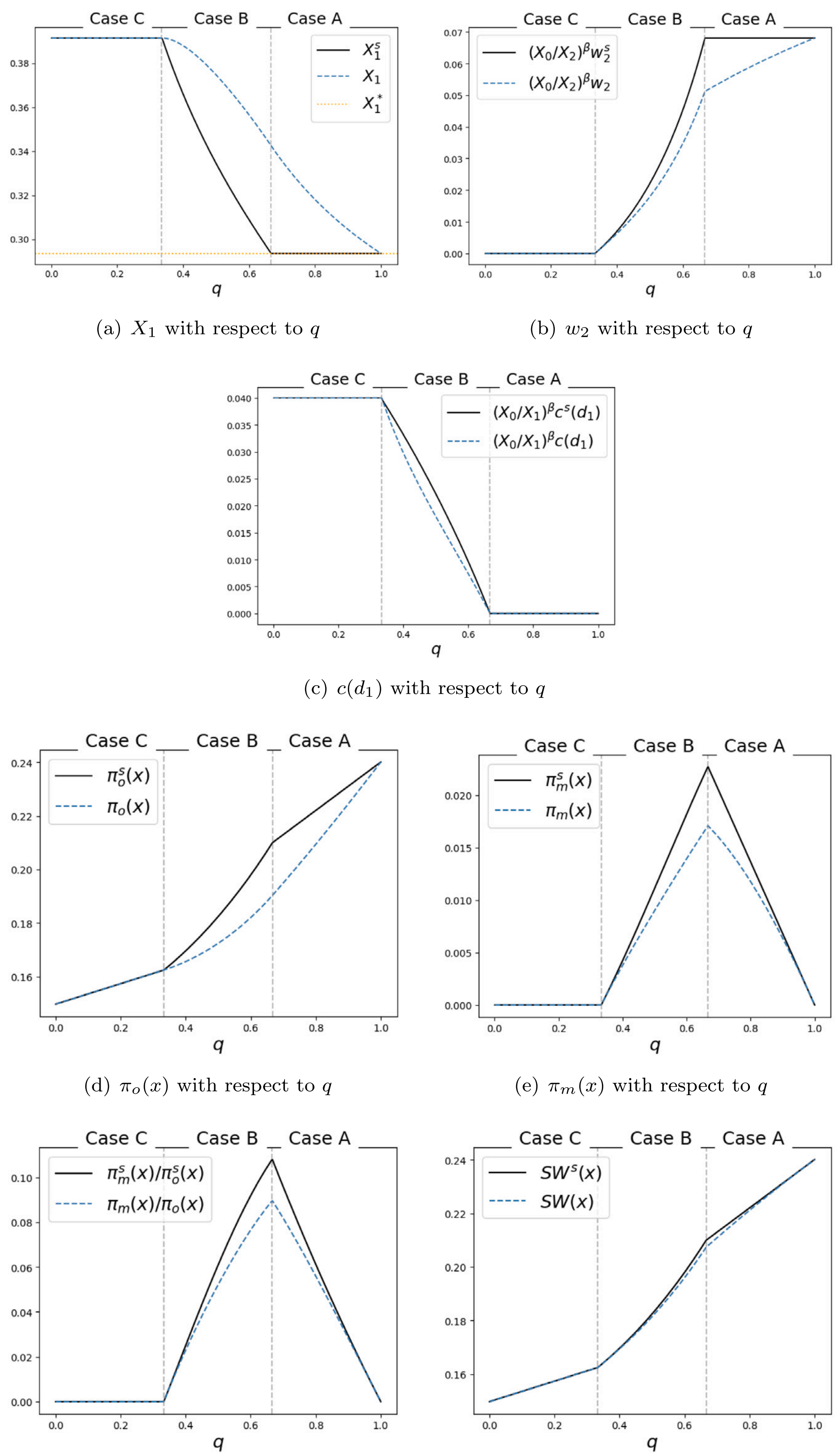
(f) π ratio with respect to σ



(g) $SW(x)$ with respect to σ

Fig. 4. Investment threshold X_1, incentive w_2, auditing cost $c(d_1)$, Owners' value $\pi_o(x)$, Managers' value $\pi_m(x)$, π ratio, and social welfare $SW(x)$ as functions of the volatility σ. Subscripts 1 and 2 denote the sustainable and unsustainable projects, respectively. The investment thresholds X_1^*, X_1, and X^s represent the benchmark solution, baseline solution, and subsidy solution for sustainable projects, respectively. The dotted, dashed, and solid lines correspond to the benchmark, baseline, and subsidy solutions. The other parameter values are set as in Table 3.

The first paradox stems from asymmetric information and cost asymmetry between project types. Sustainable projects require higher investment cost, making it unattractive for their managers to mimic unsustainable ones. In contrast, managers of unsustainable projects benefit from pretending to be sustainable. As a result, the incentive compatibility constraint applies only to the unsustainable type. The optimal contract therefore only rewards unsustainable managers who report truthfully, whereas sustainable managers receive no additional incentive because they lack the motivation to misreport. Though seemingly at odds with ESG priorities, this outcome is internally



(a) X_1 with respect to q

(b) w_2 with respect to q

(c) $c(d_1)$ with respect to q

(d) $\pi_o(x)$ with respect to q

(e) $\pi_m(x)$ with respect to q

(f) π ratio with respect to q

(g) $SW(x)$ with respect to q

Fig. 5. Investment threshold X_1, incentive w_2, auditing cost $c(d_1)$, Owners' value $\pi_o(x)$, Managers' value $\pi_m(x)$, π ratio, and social welfare $SW(x)$ as functions of the probability q. Subscripts 1 and 2 denote the sustainable and unsustainable projects, respectively. The investment thresholds X_1^*, X_1, and X^s represent the benchmark solution, baseline solution, and subsidy solution for sustainable projects, respectively. The dotted, dashed, and solid lines correspond to the benchmark, baseline, and subsidy solutions. The other parameter values are set as in Table 3.

consistent and reflects a targeted use of incentives under one-directional misreporting. If sustainable projects had lower investment costs than unsustainable ones, the incentive structure and misreporting behavior would likely change. Although this is uncommon in practice, it would alter the direction of the incentive constraint.

The second paradox relates to the role of auditing. In our model, auditing costs are pure social losses that benefit no party. At intermediate transparency, uncertainty is high enough to necessitate frequent auditing, leading to substantial welfare loss. In contrast, high transparency reduces the need for verification, whereas low transparency prompts conservative contract design that avoids costly audits altogether. Thus, extreme levels of transparency yield higher welfare than the middle range. This non-monotonic effect highlights how verification costs can distort the expected benefits of moderate disclosure. If auditing were performed by an agent who benefits from auditing fees, the costs would no longer be pure losses. This could change the welfare implications of intermediate transparency. Exploring such a model with endogenous auditors would be a fruitful extension.

Together, these findings illustrate how information asymmetry and verification costs shape incentive structures and welfare outcomes in ESG-related contracting. Although model-specific, the results offer practical insights and suggest directions for future work that relax some of the core assumptions.

6. Conclusion

This study designed an incentive-auditing contract addressing such information asymmetry within a real options model. In this model, although both the owners and managers can observe cash flows, only managers have the capability to assess ESG attributes, which determine the sustainability of these cash flows. Consequently, managers might exploit their private information concerning ESGed characteristics for inaccurate reporting to attain private benefits. The principals counteract potential agency problems by implementing optimal contracts incorporating incentives and auditing mechanisms. Additionally, we introduce government subsidies into the model to discuss the impacts of subsidy policies on the contract and social welfare. The main results of this study are summarized as follows.

ESG investments may encounter several challenges. Our investigation reveals that in optimal contracts, incentives paradoxically favor managers of unsustainable projects, whereas sustainable projects experience delays in investment timing due to owners' efforts to mitigate information costs, both of which contradict ESG principles. In terms of governance, the results show that higher corporate transparency leads to reduced incentives, a lower threshold X_1 (indicating faster investment timing in sustainable projects), higher owners' option value, and lower managers' option value. At a moderate level of corporate transparency, owners incur the highest auditing costs, which ironically results in the lowest social welfare, whereas either higher or lower transparency levels can enhance social welfare. Introducing a subsidy policy brings positive outcomes. Our model highlights the beneficial impact of subsidies on ESG investment and corporate sustainability. First, subsidies effectively promote ESG investments by accelerating the timing of sustainable projects. Second, they are particularly influential in scenarios of low corporate transparency, counteracting the drawbacks of opaque governance. Third both owners and managers benefit from these subsidies. An intriguing finding is that the subsidy policy reverses the effects of corporate transparency on sustainable investment timing and the owner's option value. Indeed, with lower corporate transparency, sustainable investment can occur earlier, and owners can obtain higher value. This implies that the subsidy policy can exacerbate the governance aspect of ESG. Regarding the probability of selecting a sustainable project, a higher q results in a lower threshold X_1, higher incentives, reduced auditing expenditure, enhanced owner's option value, and higher social welfare. However, the relationship with the manager's option value is nonlinear, and subsidies are most effective in improving social welfare at moderate q. Cash flow volatility increases delay in investment but enhances owners' option value and overall social welfare. However, managerial incentives and auditing costs peak at moderate volatility, implying that extreme uncertainty reduces contract effectiveness and weakens managerial benefits.

This study offers actionable insights into designing optimal contracts and regulatory policies to foster genuine sustainability in corporate governance. By balancing incentives with effective audit mechanisms and judiciously designed subsidies, managerial actions can be better aligned with ESG objectives, ultimately enhancing social welfare. The research provides valuable guidance for both corporate governance and policymaking. However, the study has certain limitations, such as the naive representation of ESG risk using a Poisson jump rate, which does not fully capture the richness of ESG considerations. Although the model suggests that subsidy policies can promote sustainable investments, there is a potential long-term concern about whether such compensation will implicitly tolerate opaque corporate governance. This dual effect indicates that although subsidies advance sustainable practices, they must be carefully calibrated to avoid adverse impacts on the governance aspect of ESG. Future research could expand this model by examining the long-term effects of these policies and other factors influencing ESG investment decisions. Additionally, empirical validation of these theoretical findings would enhance the robustness of the proposed framework.

CRediT authorship contribution statement

Zhongli Wang: Conceptualization, Methodology, Formal analysis, Software, Writing – original draft, Writing – review & editing, Visualization, Investigation, Project administration. **Michi Nishihara:** Conceptualization, Methodology, Formal analysis, Writing – review & editing, Funding acquisition, Project administration, Supervision.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT in order to improve language and readability. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Appendix

A.1. Proof of Proposition 1

In terms of constraints (6), considering $w_i \geq 0$, we can see the first constraint of (6) consistently holds true, thereby allowing for its exclusion from further consideration. We can also see that x can be ignored. The manager should have no incentive to fake an unsustainable project. Therefore, we can easily know that $w_1 = 0, d_2 = 0$, and only the last inequality (i.e., the incentive-compatibility condition for the manager who observes the sustainable project and may try to report as it is unsustainable project) of the optimization (5) matters.

Let $\{(X_i, w_i, d_i) \mid i = 1, 2\}$ represents the optimal solution. It immediately follows that :

$$X_2^{-\beta} w_2 - X_1^{-\beta}(\Delta I - d_1 \Gamma) = 0 \tag{8}$$

Let $\mu_i (i = 1, 2, 3)$ denote the Lagrangian multipliers, associated with the remaining constraints $w_2 \geq 0, d_1 \geq 0$, and constraint Eq. (8), respectively. We obtain the Lagrangian

$$\begin{aligned}\mathcal{L}(X_1, X_2, w_2, d_1) = {} & q X_1^{-\beta}(u_1 X_1 - I_1 - c(d_1)) \\ & + (1-q) X_2^{-\beta}(u_2 X_2 - I_2 - w_2) + \mu_1 d_1 \\ & + \mu_2 w_2 + \mu_3 (X_2^{-\beta} w_2 - X_1^{-\beta}(\Delta I - d_1 \Gamma)).\end{aligned}$$

The Karush-Kuhn–Tucker condition are (8),

$$\frac{\partial \mathcal{L}}{\partial X_1} = q(1-\beta) u_1 X_1^{-\beta} + \beta(q(I_1 + c(d_1)) + \mu_3(\Delta I - d_1 \Gamma)) X_1^{-(\beta+1)} = 0, \tag{9}$$

$$\frac{\partial \mathcal{L}}{\partial X_2} = (1-q)(1-\beta) u_2 X_2^{-\beta} + \beta((1-q)(I_2 + w_2) - \mu_3 w_2) X_2^{-(\beta+1)} = 0, \tag{10}$$

$$\frac{\partial \mathcal{L}}{\partial w_2} = \mu_2 + \mu_3 X_2^{-\beta} + (q-1) X_2^{-\beta} = 0, \tag{11}$$

$$\frac{\partial \mathcal{L}}{\partial d_1} = \mu_1 + \Gamma \mu_3 X_1^{-\beta} - q c'(d_1) X_1^{-\beta} = 0, \tag{12}$$

and

$$\mu_1 d_1 = \mu_2 w_2 = 0, \quad \mu_i \geq 0 (i = 1, 2, 3). \tag{13}$$

Now we solve (8)–(13). Firstly, it follows from (8)–(12) that:

$$w_2 = (\frac{X_2}{X_1})^\beta (\Delta I - d_1 \Gamma)$$
$$X_1 = \frac{\beta(\mu_3(\Delta I - d_1\Gamma) + qI_1 + qc(d_1))}{(\beta-1)qu_1}$$
$$X_2 = \frac{\beta((1-\mu_3-q)w_2 - (1-q)I_2)}{(\beta-1)(1-q)u_2}$$

Then, we can derive the solution of (8)–(13), depending on the region of Γ. The solution $\{(X_i, w_i, d_i) \mid i = 1, 2\}$ is derived as follows:

If $\Gamma \leq qc'(0)/(1-q)$ (denoted by *Case A*), where $\mu_1 > 0, \mu_2 = 1-q$, we have $d_1 = 0$ from (13). We also have $\mu_3 = 1-q$ from (11) and $\mu_1 = X_1^{-\beta}(qc'(0) - (1-q)\Gamma)$ from (12). Then, the solution is given as:

$$X_1 = \frac{\beta}{(\beta-1)u_1}(\frac{1-q}{q}\Delta I + I_1);$$
$$w_1 = 0;$$
$$d_1 = 0.$$
$$X_2 = X_2^* = \frac{\beta I_2}{(\beta-1)u_2};$$
$$w_2 = (\frac{X_2^*}{X_1})^\beta \Delta I;$$
$$d_2 = 0.$$

If $qc'(0)/(1-q) < \Gamma \leq \max\{\Delta I, qc'(\Delta I/\Gamma)/(1-q)\}$ (denoted by *Case B*), where $\mu_1 = \mu_2 = 0$, we have $\mu_3 = 1-q$ from (11). We can also derive d_1 by (12). Then, the solution is given as:

$$X_1 = \frac{\beta}{(\beta-1)u_1}(I_1 + c(d_1) + \frac{1-q}{q}(\Delta I - d_1\Gamma));$$
$$w_1 = 0;$$
$$d_1 = c'^{-1}(\frac{(1-q)\Gamma}{q}).$$
$$X_2 = X_2^* = \frac{\beta I_2}{(\beta-1)u_2};$$
$$w_2 = (\frac{X_2^*}{X_1})^\beta(\Delta I - d_1\Gamma);$$
$$d_2 = 0.$$

If $\Gamma > \max\{\Delta I, qc'(\Delta I/\Gamma)/(1-q)\}$ (denotedy by *Case C*), where, $\mu_1 = 0, \mu_2 > 0$, we have $w_2 = 0$ from (13). We also have $\Delta I - d_1\Gamma = 0$ from (8), $\mu_3 = qc'(d_1)/\Gamma$ from (12), and $\mu_2 = X_1^{-\beta}(1 - q - qc'(d_1)/\Gamma)$ from (11). Then, the solution is given as:

$$X_1 = \frac{\beta}{(\beta-1)u_1}(I_1 + c(d_1))$$
$$w_1 = 0;$$
$$d_1 = \frac{\Delta I}{\Gamma}.$$
$$X_2 = X_2^* = \frac{\beta I_2}{(\beta-1)u_2};$$
$$w_2 = 0;$$
$$d_2 = 0.$$

Note that if $\mu_i > 0 \quad (i = 1, 2)$, considering the restrictions defined in Eqs. (8) and (13), it results in $\Delta I = 0$. However, this result stands in contradiction to the premise that $\Delta I > 0$. In the context of real-world ESG investments, it is evident that the costs associated with sustainable projects differ significantly from those of unsustainable ones. Therefore, this scenario lacks practical relevance and will not be further discussed in our analysis.

A.2. Proof of Proposition 3

We find the optimal subsidy s in each case where $SW(x)$ is maximized. The first order condition is given as follows:

$$\frac{\partial SW}{\partial s} = \frac{\partial SW}{\partial X_1} \cdot \frac{\partial X_1}{\partial s}$$
$$= qx^\beta(-\beta X_1^{-\beta-1}(u_1X_1 - I_1 - c(d_1)) + u_1X_1^{-\beta}) \cdot \frac{-\beta}{\beta-1}u_1 = 0$$

By this, we obtain the equality:

$$X_1 = \frac{\beta}{(\beta-1)u_1}(I_1 + c(d_1)) \tag{14}$$

Substituting the values of X_1 from each case of Proposition 2 into (14), we can derive the optimal subsidy s^* as follows:

Case A:

$$s^* = \frac{1-q}{q}\Delta I.$$

Case B:

$$s^* = \frac{1-q}{q}(\Delta I - d_1\Gamma),$$

where

$$d_1 = c'^{-1}(\frac{(1-q)\Gamma}{q}).$$

Case C:

$$s^* = 0.$$

Data availability

No.

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