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This paper analyzes how ESG-linked executive compensation interacts with carbon taxation in a multitask principal-agent framework. A risk-neutral principal with financial and environmental preferences incentivizes a risk-averse manager to exert productive and abatement effort while facing an exogenous carbon tax on emissions. We show that, in the absence of ESG incentives, carbon taxes reduce emissions mainly by lowering production. In contrast, ESG-linked compensation shifts emission reductions toward increased abatement, allowing the principal to raise expected payoff while simultaneously reducing emissions, both with and without carbon taxation. However, carbon taxes narrow the range of feasible ESG preferences and, at high levels, may induce excessive abatement, potentially leading to negative net emissions. Our results highlight the importance of aligning internal incentive design with external climate regulation. The interplay of ESG compensation and carbon taxes should also be considered from a regulatory perspective.

JEL Classifications: D82, M52, Q58, Q54, H25

Keywords: *ESG-linked executive compensation, Carbon taxation, Environmental regulation, Climate policy, Managerial incentives*

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Abstract

This paper analyzes how ESG-linked executive compensation interacts with carbon taxation in a multitask principal-agent framework. A risk-neutral principal with financial and environmental preferences incentivizes a risk-averse manager to exert productive and abatement effort while facing an exogenous carbon tax on emissions. We show that, in the absence of ESG incentives, carbon taxes reduce emissions mainly by lowering production. In contrast, ESG-linked compensation shifts emission reductions toward increased abatement, allowing the principal to raise expected payoff while simultaneously reducing emissions, both with and without carbon taxation. However, carbon taxes narrow the range of feasible ESG preferences and, at high levels, may induce excessive abatement, potentially leading to negative net emissions. Our results highlight the importance of aligning internal incentive design with external climate regulation. The interplay of ESG compensation and carbon taxes should also be considered from a regulatory perspective.

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1 Introduction

In response to heightened investor attention to corporate environmental, social, and governance (ESG) performance, firms have increasingly incorporated ESG-related metrics into executive compensation schemes (Cohen et al., 2023; Ganu et al., 2023; Efing et al., 2024; Bebchuk and Tallarita, 2022). As firms possess considerable discretion in structuring these contracts, ESG-linked pay varies widely across industries and jurisdictions. Prior literature documents that more than half of large publicly listed firms now include at least one ESG metric in top executive incentive plans, with environmental measures—such as carbon intensity, absolute CO_2 emissions, energy efficiency, or progress toward net-zero targets—constituting a growing share of long-term incentive plans (Cohen et al., 2023; Ganu et al., 2023). Typical compensation structures combine fixed salary, annual cash bonuses tied to operational or financial KPIs, and long-term equity or performance-share units, increasingly augmented by explicit climate or sustainability targets. However, the precise weighting of environmental criteria remains modest and heterogeneous, and the design of such incentives often lacks standardized measurement, comparability, or enforceability.

At the same time, many jurisdictions have adopted carbon taxes or emissions prices as policy instruments to curb industrial CO_2 emissions (Timilsina, 2022; Döbbeling-Hildebrandt et al., 2024; Tax Foundation Europe, 2024). Yet these policy regimes are set at the national or regional level and often feature inconsistent coverage and heterogeneous price levels across fuel types and sectors. For example, taxes on coal, natural gas, and petroleum products are rarely harmonized within a country, and effective carbon prices across OECD economies vary by more than an order of magnitude. Similarly, estimates of the social cost of carbon emissions differ substantially (Pindyck, 2017). Furthermore, there exists regulation on the supranational level such as the Emission Trading System (ETS) and the Carbon Border Adjustment Mechanism (CBAM) of the European Union that is applied to specific industries. As a result, individual firms frequently face fragmented and imperfect price signals, even when formally subject to carbon taxation.

Although both developments—ESG-linked compensation and carbon pricing—share the overarching goal of reducing negative environmental externalities, they have evolved largely independently. This raises key conceptual questions about their interaction. Do environmental incentive contracts act as substitutes for external carbon prices—providing internal discipline where regulation is weak—or do they function as complements, becoming more effective when carbon prices amplify the marginal benefit of emissions abatement? Conversely, could the presence of a high carbon tax crowd out or diminish the need for internal environmental incentives? The optimal design of managerial compensation in carbon-regulated environments, however, remains theoretically underexplored so far.

We address these questions with a multitask principal-agent model in the tradition of the linear-exponential-normal (LEN) framework (Spremann, 1987; Holmström and Milgrom, 1991), focusing on the environmental ("E") component of ESG. In our model, a risk-neutral principal—the firm owner—operates a production process that generates CO_2 emissions and derives utility from both financial returns and environmental outcomes. A risk-averse manager exerts unobservable effort in two dimensions: (i) operational effort that increases firm output or profits, and (ii) abatement effort that reduces emissions. Both forms of effort are privately costly to the agent and not contractible. The principal therefore designs a compensation contract with linear bonuses tied to measurable performance signals, in particular, financial outcomes and emissions.

Incorporating a government-imposed carbon tax into this framework introduces a new channel through which emissions affect firm payoffs. The carbon tax alters the marginal cost of production and therefore the principal's valuation of productive effort. We characterize how optimal incentive weights on financial and environmental performance depend on external regulation. The model delivers theoretical predictions about the relation of carbon taxes and ESG-linked incentives and characterizes how the optimal contract responds to variations in carbon tax levels. Moreover, the model predicts the effect of internal incentives and external regulation on the total emission level.

This paper makes three primary contributions. First, we develop a tractable multitask principal-agent model that embeds a government-imposed carbon tax into a standard LEN framework, allowing us to study how external carbon pricing affects the optimal structure of executive incentive contracts. While existing research mostly examines ESG-linked pay or carbon taxation in isolation, our theory provides a unified framework for characterizing their interaction. Second, we identify the relation between carbon taxes and ESG-linked incentives. We show that, in general, the principal's payoff and the firm's emissions can be reduced by offering ESG-linked pay—either in a framework with or without carbon taxes. However, we also document that the typical linear contracts are not feasible to implement, if the ESG preferences of the principal are too strong or too weak. Moreover, the range of feasible contracts with ESG-linked incentives is reduced when the firm is operating in a regime with a carbon tax. Third, the model yields novel normative implications for both firms and policymakers or regulators. For firms, we derive comparative statics that inform how the weighting of environmental KPIs should adjust to different carbon-price regimes. For policymakers, the results clarify that regulatory instruments may not have the desired effect: without ESG-linked incentives, carbon taxes reduce emissions solely by reducing production levels, thereby generating potentially harmful effects for the economy. With ESG-linked incentives, the regulation on carbon taxes reduces the range of private governance mechanisms to be implemented. Taken together, our analysis provides a theoretical foundation for understanding the incentives that shape corporate decarbonization in a world where public and private climate instruments increasingly coexist.

Prior literature suggests that incorporating ESG performance metrics into executive compensation can help address the multi-dimensional interests of shareholders. For instance, Bonham and Riggs-Cragun (2024) develop a theoretical framework outlining several rationales for integrating ESG-related components into managerial compensation contracts. Among these rationales are (1) the presence of shareholders who intrinsically value ESG outcomes and (2) the operation of firms in jurisdictions that impose a carbon tax. However, Bonham and Riggs-Cragun (2024) examine these motivations in isolation and do not consider potential interactions between them.

Aresu et al. (2023) conduct an empirical analysis examining the extent to which regulatory pressure encourages firms to incorporate corporate social responsibility (CSR) criteria into executive compensation, and they document a positive association between the two. However, they explicitly note that "[f]rom a theoretical perspective, it remains unclear how firms engage with social and environmental regulatory pressures" (Aresu et al., 2023, 2768). In particular, it remains an open question whether firms employ CSR contracting as a substitute for insufficient regulation or, alternatively, adopt CSR contracting to align with existing regulatory requirements.

Bebchuk and Tallarita (2022) adopt a more skeptical stance toward the implementation of ESG-based compensation, characterizing it as "a questionable promise [that] poses significant perils" (Bebchuk and Tallarita, 2022, 37). At the same time, they acknowledge that stakeholders' interests are multi-dimensional and that incorporating diverse performance metrics into executive compensation is, in principle, consistent with theoretical recommendations. A central concern arising from their empirical analysis is that ESG metrics often lack transparency and are difficult for shareholders to observe and evaluate, thereby limiting effective scrutiny. Moreover, they argue that the inclusion of ESG metrics in compensation contracts may not adequately reflect the preferences of all shareholders, but rather primarily those of a small subset.

Our work also relates to the canonical environmental economics literature on carbon taxation and optimal environmental regulation. Pigouvian taxes have long been recognized as a first-best instrument for internalizing environmental externalities (Pigou, 1932). Empirical studies document heterogeneous firm responses to carbon pricing, shaped by sectoral characteristics, input substitutionality, and regulatory design features. Metcalf (2021) reviews a range of empirical analyses examining the effects of carbon tax introductions on emission levels. Overall, prior evidence indicates that carbon taxes do reduce emissions; however, as Metcalf (2021) emphasizes, only a limited number of countries have implemented carbon taxes at sufficiently high levels to generate substantial emission reductions. While this literature primarily focuses on firms' production and abatement decisions under carbon pricing, it typically abstracts from internal organizational incentives. We extend this theoretical framework by embedding a carbon tax directly into a principal-agent setting, thereby allowing us to characterize how the firm's internal governance structures interact with external regulatory instruments.

Recent theoretical work related to ESG-linked compensation and carbon taxation within a principal-agent framework has been performed, e.g., by Chaigneau and Sahuguet (2025) and Bonham and Riggs-Cragun (2025). Chaigneau and Sahuguet (2025) develop a principal-agent model to analyze contractual incentives for ESG performance. Unlike in our setting, their framework assumes that the agent exerts productive effort that enhances financial performance and makes investment decisions that improve the firm's ESG performance, with the latter being privately observed by the manager. Both types of actions influence the firm's stock price, which in turn determines compensation. Moreover, Chaigneau and Sahuguet (2025) do not incorporate any form of exogenous regulation such as carbon taxes into their analysis.

Closely related to our analysis is the principal-agent framework developed by Bonham and Riggs-Cragun (2025). They examine a multitasking model in which an agent can influence various moments of normally distributed variables and analyze how regulation and contractual incentives jointly shape financial and ESG-related activities. Their primary objective is to move beyond the classic trade-off between financial and ESG goals by conceptualizing green innovation as a mechanism that increases the correlation between financial and ESG performance. Accordingly, their analysis focuses on the incentives for such innovative activities. The regulatory instrument they consider is an income tax linked to ESG performance, creating an additional connection between financial and ESG outcomes through external regulation—albeit one that may be difficult to implement in practice. While our general framework can be viewed as a special case of the broader model in Bonham and Riggs-Cragun (2025), our focus remains on the traditional trade-off between financial and ESG incentives—an effect that is also empirically documented (Homroy et al. 2023). We analyze how external regulation in the form of a carbon tax interacts with contractual ESG incentives. A key performance metric in our setting is the total emissions generated under different combinations of regulation and incentives, which Bonham and Riggs-Cragun (2025) do not address but which is central to the policy goal of emission reduction.

By formalizing the interaction between internal managerial incentives and external carbon taxation—as well as their joint effects on emission levels—our theoretical contribution helps bridge the literature on corporate governance and executive compensation in multitasking settings (Holmström and Milgrom, 1991; Feltham and Xie, 1994; Prendergast, 1999; Edmans and Gabaix, 2016) with the environmental economics literature on carbon pricing, Pigouvian taxation, and firms' abatement responses to regulatory instruments (Goulder and Schein, 2013; Aldy and Stavins, 2012). Our results speak directly to ongoing policy debates about whether private governance mechanisms can complement weak or politically constrained climate policies, and how firms should optimally design executive compensation in the presence of external climate regulation.

2 Model Setup

We employ a multitask principal-agent model in which a risk-neutral principal—representing shareholders with multi-dimensional preferences—contracts with a risk- and effort-averse agent, the manager, to exert two distinct types of effort. First, the agent supplies productive effort (a_1), which increases the firm's financial performance but, due to the nature of the production process, inevitably generates emissions. Second, the agent can exert abatement effort (a_2) aimed at reducing the emissions associated with production. While we allow the principal to derive utility from both financial and ESG outcomes, we assume that the manager has only monetary interests.

To analyze the interaction between financial incentives, ESG-related incentives, and carbon taxes, we extend the basic multitask principal-agent model of Holmström and Milgrom (1991), that was augmented, for example, by Ewert and Wagenhofer (2025) along several dimensions. First, we incorporate ESG preferences into the principal's objective function by assuming that the principal—beyond maximizing financial value—also has ecological preferences and seeks to reduce emissions. Second, we allow the principal to incentivize both financial and ESG-related outcomes. While this mitigates the effort-allocation distortions typically inherent in multitasking environments, it also implies that the agent exerts abatement effort only when explicitly incentivized to do so. Third, we introduce a carbon tax to capture exogenous regulatory pressure on emissions.

The agent's effort choices are unobservable to the principal. However, the firm's output is contractible and is given by

$$x = (b_1 - p)a_1 + \varepsilon_x,$$

where a_1 denotes the agent's productive effort, $b_1 > 0$ captures the productivity of this effort, and $\varepsilon_x \sim N(0, \sigma_x^2)$ represents uncontrollable shocks outside contracting parties' influence. The parameter p reflects the carbon tax the firm must pay per unit of emissions generated by the production process.[1] Emissions are determined by

$$e = b_3 a_1 - b_2 a_2 + \varepsilon_e,$$

where b_3 measures the effect of productive effort on emissions.[2] For simplicity, we normalize $b_3 = 1$, implying that each unit of productive effort generates one unit of emissions and thus causes a corresponding carbon tax liability for the firm. The parameter $b_2 > 0$ captures the

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[1] Note that if the carbon tax would exceed the productivity of the agent's effort, i.e., $b_1 < p$, the firm would not be able to operate in a profitable manner.

[2] For reasons of comparability, emissions are converted to monetary units. For example, 1 kg of CO_2 emissions is proportional to a given Dollar amount.

impact of abatement effort on emission reduction,[3] while $\varepsilon_e \sim N(0, \sigma_\varepsilon^2)$ represents noise in the measurement of emissions. The level of emissions is measurable and contractible, and thus provides a noisy signal of the agent's abatement effort. We assume that output shocks and emission noise are uncorrelated: $Cov(\varepsilon_x, \varepsilon_e) = 0$.

The agent receives a linear compensation contract of the form

$$w = v \cdot x - \beta \cdot e + f,$$

where v denotes the incentive coefficient tied to the firm's output, β the incentive coefficient associated with emissions, and f the fixed payment required to satisfy the agent's participation constraint. Exerting productive and abatement effort imposes personal costs on the agent given by

$$c = \frac{1}{2}\left(a_1^2 + a_2^2\right).$$

We assume no complementarities or substitutional relations among these two effort choices; that is, the total cost is separable in a_1 and a_2.

The principal is risk-neutral and her preferences depend on financial outcomes and emissions (see, for example, Kasmanhuber 2023; Ewert and Wagenhofer 2025):

$$UP = E[x - w - \alpha \cdot e].$$

The parameter α captures the strength of the principal's ESG preferences, with $0 < \alpha$. Higher values of α indicate stronger ESG preferences, as emissions more strongly reduce the principal's utility. The agent is risk-averse and his preferences can be characterized by a negative-exponential utility function, which yields the following certainty equivalent:

$$CE = E[w] - c - \frac{r}{2} \cdot Var[w].$$

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[3] In contrast to Ewert and Wagenhofer (2025), we do not take operating and environmental synergies into account.

The agent's utility increases in the expected wage $E[w]$, but decreases with effort costs c and the risk premium associated with bearing compensation risk, which includes the agent's coefficient of absolute risk aversion r. We assume the agent's reservation wage to be zero and independent of taxation: $\underline{u} = 0$.

The principal therefore solves the following optimization problem:

$$E[UP \mid v, \beta, f] = \max_{v,\beta,f} UP = E[x - w - \alpha \cdot e] \tag{1}$$

$$\text{s.t.} \quad E[w] - c - \frac{1}{2} r \cdot Var[w] \geq \underline{u} = 0 \tag{2}$$

$$a \in \arg\max_{a'_1, a'_2} \{E[w] - c - \frac{1}{2} r \cdot Var[w] \mid a'_1, a'_2 \in \mathbb{R}_+\} \tag{3}$$

To analyze the interplay between financial incentives, ESG-related incentives, and carbon taxes, we adopt a stepwise approach and adjust the assumptions of the basic model accordingly. We assume that the principal always provides financial incentives tied to the firm's output x. To assess how the introduction of a carbon tax affects output and emission levels, we first introduce Model A1, which represents a setting without a carbon tax and with purely financial incentives. We then compare these results to Model A2, which adds a carbon tax to the framework of A1.

Subsequently, we examine the role of ESG-related incentives in both regulatory environments. Model B1 therefore captures a setting without carbon taxes but with ESG-related incentives, while Model B2 introduces carbon taxation into the structure of B1.

This model structure enables us to address several questions by comparing outcomes across the different setups. Comparing A1 and A2 allows us to examine the impact of introducing a carbon tax in an environment where managerial compensation is tied solely to financial performance. The comparison of B1 and B2 provides an analogous assessment, but in a setting where firms also employ ESG-related compensation. Contrasting A1 with B1 (and A2 with B2) allows us to evaluate whether the introduction of ESG-related incentives affects production and emissions in the absence (presence) of carbon taxes. We next derive the general solutions for the four model setups, solving for the optimal contract, the principal's expected payoff, and the expected emission level.

3 Analysis

3.1 Financial Incentives and Carbon Tax

We begin by presenting the solution to Model A1, which represents a standard principal-agent framework augmented only by the principal's ESG preferences. In Model A1, $p = 0$, meaning that the firm does not face a carbon tax. Moreover, because the principal provides compensation solely based on output x, the agent has no incentive—neither intrinsic nor extrinsic—to engage in abatement effort. Consequently, $\beta = 0$ and $a_2 = 0$, and the resulting emission level e is entirely determined by productive effort. Lemma 1 summarizes the results.

Lemma 1 *A risk-neutral principal with both financial and ESG preferences offers a contract based solely on financial output to a risk- and effort-averse agent. The optimal incentive rate on financial performance is*

$$v_{A1} = \frac{b_1(b_1 - \alpha)}{b_1^2 + r\sigma_x^2}, \tag{4}$$

which yields the following expected payoff for the principal:

$$UP_{A1} = \frac{b_1^2(b_1 - \alpha)^2}{2(b_1^2 + r\sigma_x^2)}. \tag{5}$$

The corresponding expected emission level resulting from productive effort is

$$e_{A1} = \frac{b_1^2(b_1 - \alpha)}{b_1^2 + r\sigma_x^2}. \tag{6}$$

All proofs are shown in the appendix.

Note that the incentive rate v_{A1} retains the core properties of the standard solution in a moral hazard framework but additionally incorporates the principal's ESG preferences through the parameter α. Intuitively, stronger ESG preferences reduce the optimal incentive rate v_{A1}, as higher incentives for productive effort would induce the agent to generate more emissions. Thus, the optimal incentive rate reflects the principal's trade-off between financial and ESG objectives. We assume that the principal does not have excessive ESG preferences, i.e., $\alpha < b_1$. Otherwise, she would not implement Model A1.

We now turn to Model A2, which introduces a carbon tax p into the preceding setup. Lemma 2 presents the corresponding results.

Lemma 2 *A risk-neutral principal with both financial and ESG preferences offers a contract based solely on financial output to a risk- and effort-averse agent. If the principal is subject to a carbon tax p per emission unit, the optimal contract specifies*

$$v_{A2} = \frac{(b_1 - p)(b_1 - p - \alpha)}{(b_1 - p)^2 + r\sigma_x^2} \tag{7}$$

leading to an expected payoff for the principal of

$$UP_{A2} = \frac{(b_1 - p)^2(b_1 - p - \alpha)^2}{2[(b_1 - p)^2 + r\sigma_x^2]} \tag{8}$$

and an expected emission level of

$$e_{A2} = \frac{(b_1 - p)^2(b_1 - p - \alpha)}{(b_1 - p)^2 + r\sigma_x^2}. \tag{9}$$

Comparing Lemmas 1 and 2 shows that the introduction of a carbon tax simply reduces the agent's financial productivity. The productivity coefficient b_1 in Model A1 is replaced by $b_1 - p$ in Model A2.

For the optimal contract to be implementable, the principal's ESG preferences must be sufficiently moderate relative to the difference between the agent's productivity and the carbon tax, i.e., $\alpha < b_1 - p$, which is more restrictive than for Model A1. While we acknowledge that non-linear contractual forms may offer greater generality (see, for example, Bonham and

Riggs-Cragun, 2025), our objective is to derive empirically testable predictions that can be evaluated with available data. Because executive compensation contracts are predominantly linear in practice, examining the interaction between linear contracts and carbon taxation provides a particularly relevant and analytically tractable framework.

The introduction of a carbon tax is generally costly for the principal. Consequently, production becomes less attractive, leading the principal to offer a lower incentive rate, which in turn reduces both productive effort and emissions. Proposition 1 formalizes these results.

Proposition 1 *In a setting with financial incentives only, the introduction of a carbon tax* $p > 0$ *reduces the agent's incentive rate, the principal's expected utility, and emissions, i.e.,* $v_{A2} < v_{A1}$*,* $UP_{A2} < UP_{A1}$*, and* $e_{A2} < e_{A1}$*. More generally, the agent's incentive rate, the principal's expected utility, and emissions are all decreasing in the carbon tax rate:* $\frac{\partial v_{A2}}{\partial p} < 0$*,* $\frac{\partial UP_{A2}}{\partial p} < 0$*, and* $\frac{\partial e_{A2}}{\partial p} < 0$*.*

Overall, the introduction of a carbon tax achieves its intended objective of reducing emissions. However, this effect is reached at the cost of lower production levels, generating potentially harmful effects for the economy. We now turn to cases in which the principal can provide ESG-related incentives that motivate the agent to engage in abatement effort, thereby reducing the emission intensity of production.

3.2 ESG-related Incentives

If the principal has the possibility to design ESG-related compensation, the agent will allocate effort between productive and abatement activities according to the incentives specified in the contract. Notably, the standard effort-allocation problem known from multitasking models (for example, Holmström and Milgrom, 1991) does not arise in our setting, as the principal can employ two distinct performance measures to fine-tune each type of effort separately.

The resulting optimal contract, the principal's expected payoff, and the expected emission level of Model B1 (i.e., without carbon taxes) are summarized in Lemma 3.

Lemma 3 *A risk-neutral principal with both financial and ESG preferences offers a contract consisting of financial and ESG-related incentives. The optimal bonus rates are given by*

$$v_{B1} = \frac{b_1^2 b_2^2 + b_1(b_1 - \alpha) r\sigma_\varepsilon^2}{(b_1^2 + r\sigma_x^2)(b_2^2 + r\sigma_\varepsilon^2) + r\sigma_x^2} \tag{10}$$

and

$$\beta_{B1} = \frac{\alpha b_1^2 b_2^2 - \left[b_1 - \alpha(1 + b_2^2)\right] r\sigma_x^2}{(b_1^2 + r\sigma_x^2)(b_2^2 + r\sigma_\varepsilon^2) + r\sigma_x^2}. \tag{11}$$

The resulting expected payoff for the principal is

$$UP_{B1} = \frac{b_1^2 b_2^2 \left[(b_1 - \alpha)^2 + \alpha^2 b_2^2\right] + \left[b_1 - \alpha\left(1 + b_2^2\right)\right]^2 r\sigma_x^2 + b_1^2 \left(b_1 - \alpha\right)^2 r\sigma_\varepsilon^2}{2\left[\left(b_1^2 + r\sigma_x^2\right)\left(b_2^2 + r\sigma_\varepsilon^2\right) + r\sigma_x^2\right]} \tag{12}$$

and the expected emission level equals

$$e_{B1} = \frac{b_1^2 b_2^2 \left[b_1 - \alpha\left(1 + b_2^2\right)\right] + \left(1 + b_2^2\right)\left[b_1 - \alpha\left(1 + b_2^2\right)\right] r\sigma_x^2 + b_1^2 \left(b_1 - \alpha\right) r\sigma_\varepsilon^2}{\left(b_1^2 + r\sigma_x^2\right)\left(b_2^2 + r\sigma_\varepsilon^2\right) + r\sigma_x^2}. \tag{13}$$

In Model B1, the principal's dual objectives can be addressed with greater precision than in Models A1 and A2 by decoupling the incentive scheme and targeting financial performance and abatement effort separately rather than jointly. This constitutes a structural distinction from Model A2, in which emission reductions are inherently linked to, and can only be attained through, a contraction in production. As indicated by equations (10) and (11), an increase in ESG preferences α leads to a reduction in financial incentives v_{B1} and a corresponding increase in emission reduction incentives β_{B1}. Furthermore, the presence of both productivity parameters b_1 and b_2, as well as the variances σ_x^2 and σ_ε^2, within each incentive component highlights the nuanced interdependencies between the different types of effort.

For the contract specified in Lemma 3 to be implementable, the principal's ESG preferences must lie within a specific range. In particular, there exists a critical lower bound $\underline{\alpha} = \dfrac{b_1 r \sigma_x^2}{b_1^2 b_2^2 + (1 + b_2^2) r \sigma_x^2} > 0$ and a critical upper bound $\overline{\alpha} = b_1 \left(1 + \dfrac{b_2^2}{r \sigma_\varepsilon^2}\right) > b_1$ such that the optimal contract is feasible only if $\underline{\alpha} < \alpha < \overline{\alpha}$.[4]

The feasibility corridor $\underline{\alpha} < \alpha < \overline{\alpha}$ is defined as the interval of ESG preference parameters for which non-negative optimal incentive rates emerge. This corridor reflects two opposing constraints that arise when the principal provides both financial and ESG-related incentives. If the principal's ESG preferences are too weak ($\alpha < \underline{\alpha}$), she places insufficient value on emission reductions to justify offering a positive incentive on the emission measure. In this case, the optimal contract would prescribe a negative ESG-related incentive, which is infeasible because it would encourage the agent to increase emissions rather than engage in abatement. Technically, a negative bonus rate is associated with an economically undefined negative effort. Conversely, if the principal's ESG preferences are too strong ($\alpha > \overline{\alpha}$), the principal would ideally like to impose an ESG incentive that is so strong that the corresponding incentive rate on financial output would become negative. As a consequence, the agent would find it optimal to exert excessively high abatement effort relative to productive effort, thereby reducing overall output. Thus, the upper bound ensures that the principal's ESG preferences do not induce contract parameters that become negative. Taken together, the corridor guarantees that the principal values emissions reduction sufficiently to make ESG incentives meaningful, but not so strongly that the resulting contract becomes infeasible or generates inefficient distortions in effort allocation.

The critical lower bound for Model B1 $\underline{\alpha} > 0$ is more restrictive and the critical upper bound $\overline{\alpha} > b_1$ is less restrictive than in Model A1, where the feasibility corridor is simply $0 < \alpha < b_1$. Whether the interval width is smaller or larger than in Model A1 depends on the productivities, risk aversion, and variances. The interval width for Model B1 $\overline{\alpha} - \underline{\alpha}$ is larger than in Model A1 if the condition $b_1^2 b_2^4 \geq r\sigma_x^2 \left[r\sigma_\varepsilon^2 - b_2^2 \left(1 + b_2^2\right)\right]$ holds.

Comparing the principal's payoff and emission levels in cases A1 and B1 yields the results

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[4] We show in Appendix A.7 that $\overline{\alpha} > \underline{\alpha} \ \forall \ b_1, b_2, r, \sigma_x, \sigma_\varepsilon > 0$

summarized in Proposition 2.

Proposition 2 *A risk-neutral principal with financial preferences and with ESG preferences in the feasible range* $\underline{\alpha} < \alpha < \overline{\alpha}$ *increases her expected payoff while simultaneously reducing emissions when offering ESG-related compensation to the agent, compared to a contract with financial incentives only.*

Proposition 2 demonstrates that aligning the principal's ESG preferences with the structure of the contract strictly improves her position. Consequently, firms that pursue ESG-related objectives should incorporate these preferences explicitly into managerial incentive schemes, as doing so enhances both economic and environmental performance.

It is important to emphasize that the positive effects described in Proposition 2 arise only if the principal's ESG preferences lie within the feasibility corridor established above, as otherwise, the optimal contract would imply negative incentive rates and economically undefined negative effort levels. From a practical perspective, these feasibility constraints provide guidance for when the use of ESG-linked compensation is likely to be effective. First, firms whose ESG orientation is too weak should not expect meaningful improvements in environmental outcomes merely by adding symbolic or low-powered ESG components to executive pay. In such cases, adjustments to corporate strategy or internal governance structures may be required before compensation design can play a meaningful role. Second, excessively strong ESG preferences may lead firms to adopt compensation schemes that are either too complex, too costly, or inconsistent with managerial participation constraints. This highlights the need for boards and compensation committees to calibrate the strength of ESG incentives carefully, ensuring that they meaningfully influence managerial behavior without undermining contract feasibility. Overall, the feasibility corridor underscores that ESG-linked compensation is not universally optimal but is most effective when aligned with a firm's underlying preferences and its capacity to implement high-powered, multi-dimensional incentive schemes.

Empirically, recent evidence on the effectiveness of ESG-linked compensation is consistent with this theoretical perspective (Shabbir et al., 2024; Efing et al., 2024; Cunbo et al., 2025). Firms that adopt such contracts typically exhibit a prior strategic commitment to environmental or sustainability goals, suggesting that their underlying preference parameter α lies within a range that makes ESG incentives both credible and implementable. Moreover, the efficacy of ESG-linked pay appears to depend critically on the precision and verifiability of ESG performance metrics, aligning with the model's emphasis on the information structure. Where measurement noise is high or ESG outcomes are difficult to attribute to managerial actions, firms tend to rely on softer governance mechanisms—such as internal sustainability committees or qualitative performance assessments—rather than high-powered incentives.

In practice, compensation committees increasingly adopt multi-metric scorecards that combine financial KPIs with environmental indicators, often weighting ESG components between 10% and 30% of total variable compensation. This is broadly consistent with the feasibility constraints derived above: moderate weights allow firms to influence effort allocation without overburdening the contract with excessive risk or conflicting objectives. Furthermore, many firms implement ESG incentives only after first establishing internal reporting systems and audit mechanisms capable of generating reliable signals of abatement or emissions performance. This mirrors the model's requirement that abatement effort be contractible (albeit noisily) and that bonus rates be chosen in light of the statistical properties of available performance measures.

Overall, the empirical landscape suggests that ESG-linked compensation is most effective when embedded within a broader strategic and organizational architecture that supports precise measurement, credible commitment to sustainability objectives, and a balanced incentive structure. This reinforces the theoretical insight that the benefits of ESG incentives emerge only when the firm's underlying preferences and information conditions fall within the feasible region derived in the model.

3.3 Carbon Tax and ESG-related Incentives

We next reintroduce a carbon tax into the previous setting to derive the solution to Model B2. If the principal is subject to a carbon tax and has the possibility to design ESG-related compensation, Lemma 4 summarizes the resulting optimal contract as well as the expected payoff and the associated level of emissions.

Lemma 4 *A risk-neutral principal with both financial and ESG preferences offers a contract consisting of financial and ESG-related incentives. If the principal is subject to a carbon tax p per emission unit, she optimally offers bonus rates*

$$v_{B2} = \frac{(b_1 - p)\, b_2^2 + (b_1 - p)\,(b_1 - p - \alpha) r\sigma_\varepsilon^2}{\left[(b_1^2 - p) + r\sigma_x^2\right](b_2^2 + r\sigma_\varepsilon^2) + r\sigma_x^2} \tag{14}$$

and

$$\beta_{B2} = \frac{(b_1 - p)\, \alpha b_2^2 - \left[b_1 - p - \alpha(1 + b_2^2)\right] r\sigma_x^2}{\left[(b_1^2 - p) + r\sigma_x^2\right](b_2^2 + r\sigma_\varepsilon^2) + r\sigma_x^2}. \tag{15}$$

The resulting expected payoff for the principal is

$$\begin{aligned} UP_{B2} \quad = \quad & \frac{(b_1 - p)^2\, b_2^2 \left[(b_1 - p - \alpha)^2 + \alpha^2 b_2^2\right] + \left[b_1 - p - \alpha\,(1 + b_2^2)\right]^2 r\sigma_x^2}{2\left[(b_1^2 + r\sigma_x^2)(b_2^2 + r\sigma_\varepsilon^2) + r\sigma_x^2\right]} \\ & + \frac{(b_1 - p)^2\,(b_1 - p - \alpha)^2\, r\sigma_\varepsilon^2}{2\left[(b_1^2 + r\sigma_x^2)(b_2^2 + r\sigma_\varepsilon^2) + r\sigma_x^2\right]} \end{aligned} \tag{16}$$

and the expected level of emissions is

$$\begin{aligned} e_{B2} \quad = \quad & \frac{(b_1 - p)^2\, b_2^2 \left[b_1 - p - \alpha\,(1 + b_2^2)\right] + (1 + b_2^2)\left[b_1 - p - \alpha\,(1 + b_2^2)\right] r\sigma_x^2}{(b_1^2 + r\sigma_x^2)(b_2^2 + r\sigma_\varepsilon^2) + r\sigma_x^2} \\ & + \frac{(b_1 - p)^2\,(b_1 - p - \alpha)\, r\sigma_\varepsilon^2}{(b_1^2 + r\sigma_x^2)(b_2^2 + r\sigma_\varepsilon^2) + r\sigma_x^2}. \end{aligned} \tag{17}$$

A technical comparison of Lemma 4 with Lemma 3 shows that the introduction of a carbon tax reduces the financial productivity parameter by replacing b_1 with $b_1 - p$, reflecting the relationship already observed between Lemmas 1 and 2. Furthermore, contrasting the results of Model B2 in Lemma 4 with those of Model A2 in Lemma 2 highlights that the presence of an additional incentive rate enables the principal to implement a more precise alignment of incentives with her objectives.

As in the previous cases, the principal's ESG preferences must remain within specific boundaries for the optimal contract to be implementable. Formally, the feasibility condition requires $\underline{\alpha'} = \dfrac{(b_1 - p)r\sigma_x^2}{(b_2^2 + 1)r\sigma_x^2 + (b_1 - p)^2 b_2^2} < \alpha < (b_1 - p)\left(1 + \dfrac{b_2^2}{r\sigma_\varepsilon^2}\right) = \overline{\alpha'}$. Preferences below $\underline{\alpha'}$ would render ESG-related incentives too weak (i.e., negative), while preferences above $\overline{\alpha'}$ would push the contract part on financial incentives outside the allowable range.

It is instructive to compare the feasibility corridor for the ESG preferences in the presence of a carbon tax, $[\underline{\alpha'}, \overline{\alpha'}]$, with the corresponding corridor in the absence of a carbon tax, $[\underline{\alpha}, \overline{\alpha}]$.

Proposition 3 *The lower critical bound $\underline{\alpha'}$ is non-monotonous in the carbon tax rate. The upper critical bound $\overline{\alpha'}$ and the range of ESG preference parameters for which contract B2 remains feasible $\overline{\alpha'} - \underline{\alpha'}$ decrease in the carbon tax rate.*

Intuitively, introducing a carbon tax reduces the effective productivity of the agent's effort, as each unit of output generates additional costs through the tax. As a result, the lower bound $\underline{\alpha'}$ is generally higher than $\underline{\alpha}$ (provided the agent is risk-averse). Conversely, the upper bound $\overline{\alpha'}$ is always lower than $\overline{\alpha}$, since excessively strong ESG preferences combined with the carbon tax could push the contract beyond feasible incentive levels. Taken together, the corridor $[\underline{\alpha'}, \overline{\alpha'}]$ is narrower than $[\underline{\alpha}, \overline{\alpha}]$, indicating that the introduction of a carbon tax constrains the design of an implementable ESG-linked contract. This highlights a key trade-off: while carbon taxes provide an external incentive to reduce emissions, they simultaneously reduce the range of ESG preference parameters for which a feasible and effective incentive contract can be designed. From an ecological perspective, however, less ESG incentives are needed when a carbon tax is adequately chosen to internalize externalities.

Moreover, due to its non-monotonicity, the lower bound $\underline{\alpha'}$ can have an interior maximum in the interval $p \in [0, b_1]$. If the principal's actual ESG parameter α is smaller than this maximum there exists a sub-interval of carbon tax rates for which Model B2 is undefined, because the bonus rate would be negative. A numerical example is shown in Figure 1.

- - - Insert Figure 1 about here - - -

We now examine whether the result presented in Proposition 2 also holds in the presence of a carbon tax. A comparison of Models A2 and B2 shows that, even when the principal faces a carbon tax regime, the introduction of ESG-related incentives increases her expected payoff while simultaneously reducing the emissions associated with production. Proposition 4 summarizes the result that is indeed analogous to Proposition 2.

Proposition 4 *A risk-neutral principal with financial preferences and with ESG preferences in the feasible range* $\underline{\alpha'} < \alpha < \overline{\alpha'}$ *who operates under a carbon tax regime increases her expected payoff while simultaneously reducing emissions by offering ESG-related compensation to the agent, compared to the setting with only financial preferences.*

We now turn to the comparison of Models B1 and B2 to assess whether the introduction of a carbon tax can further reduce emissions when the principal can implement a contractual design that incentivizes the agent to undertake abatement effort. Recall from Proposition 1 that the carbon tax reduced emissions by lowering overall production, rather than by making production itself less emission-intensive. The key question here is whether a carbon tax can generate a similar additional reduction in emissions once the principal already provides explicit incentives for the agent to decarbonize.

Proposition 5 *In a setting with financial and ESG-related incentives, the introduction of a carbon tax lowers emissions and has an ambiguous effect on the principal's utility. More generally, emissions are decreasing in the carbon tax rate, the principal's expected payoff can be decreasing or increasing in the carbon tax rate.*

Figure 2 illustrates the principal's payoff in the four scenarios. The figure shows that the principal's payoff is always higher without carbon taxes. Moreover, while the principal's payoff strictly decreases in the carbon tax when she can offer only financial incentives, her payoff may decrease, but also increase in p when she has the possibility to provide financial and ESG-related incentives to the agent.

- - - Insert Figure 2 about here - - -

As in the case of financial incentives only, the introduction of a carbon tax achieves its intended goal of reducing emissions. However, unlike the purely financial-incentive setting, emission reductions are not driven solely by a contraction in productive incentives. Instead, the presence of ESG-related compensation allows the principal to respond to higher carbon taxes by strengthening incentives for abatement effort. For sufficiently high carbon tax levels, the optimal contract may even induce negative net emissions.

As shown in Proposition 4, the principal is strictly better off offering ESG-related compensation when operating under a carbon tax regime. At the same time, rising carbon taxes can lead the principal to over-incentivize abatement effort, shifting emission reductions away from efficiency improvements in production (see Figure 3).

- - - Insert Figure 3 about here - - -

In our model, negative emissions should be interpreted as investments in activities that go beyond merely reducing production-related emissions, such as carbon capture and storage (CCS), direct air capture (DAC), offsetting, or other carbon-removing technologies. The result that high carbon taxes induce "over-abatement" does therefore not imply physical infeasibility, but rather reflects the incentive to allocate additional resources toward emission removal once emissions are already fully mitigated at the margin. In extreme cases, emission reduction can become the firm's main business model.[5]

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[5] Regulatory credits for the production of electric vehicles contributed \$2,763m to \$7,076m income from operations of Tesla Inc. in the fiscal year 2024.

4 Conclusion

This paper studies how internal ESG-related compensation schemes interact with external carbon taxation within a multitask principal-agent framework. By embedding a carbon tax into a linear-exponential-normal (LEN) model with productive and abatement effort, we provide a unified theory of how managerial incentives, shareholder ESG preferences, and public climate policy jointly shape production, emissions, and firm payoff.

Three central insights emerge. First, in the absence of ESG-linked incentives, carbon taxes reduce emissions primarily by dampening productive effort. While effective in lowering emissions, this channel operates through a contraction of output and a decline in the principal's expected payoff, creating potentially harmful effects for the economy. Second, allowing the principal to condition compensation on environmental performance fundamentally alters this trade-off. When ESG preferences are moderate, ESG-linked compensation strictly dominates purely financial incentives: the principal can increase her expected payoff while simultaneously reducing emissions, both with and without carbon taxation. Emission reductions in this case arise from cleaner production (or carbon removal) rather than from lower production.

Third, carbon taxation and ESG-linked compensation are neither pure substitutes nor pure complements. Introducing a carbon tax in an environment with ESG incentives further reduces emissions, but it also tightens the feasibility constraints on incentive design. Higher carbon taxes reduce the effective productivity of managerial effort and shrink the range of ESG preferences for which linear incentive contracts remain implementable. Moreover, sufficiently high carbon taxes may induce the principal to over-incentivize abatement effort, leading to negative net emissions. In economic terms, this reflects a shift toward activities such as carbon capture, offsetting, or other negative-emission technologies once marginal production-related emissions are fully mitigated.

Taken together, the analysis highlights that internal governance mechanisms and external regulation interact in subtle ways. ESG-linked compensation can amplify the effectiveness of carbon taxes by redirecting managerial effort toward abatement rather than merely scaling down production. At the same time, external regulation constrains the set of preference parameters under which such contracts can be feasibly and efficiently implemented.

Several limitations of the analysis point to natural directions for future research. First, we restrict attention to linear incentive contracts. While this choice is well motivated by the structure of executive compensation observed in practice, non-linear contracts or bonus schemes with thresholds and caps may relax or tighten some of the feasibility constraints identified in the model. Allowing for richer contractual forms could mitigate the narrowing of the ESG-preference corridor under carbon taxation.

Second, the model abstracts from dynamic considerations. In reality, ESG investments and abatement efforts often involve long-term projects with intertemporal spillovers, learning effects, or irreversible costs. A dynamic framework could capture how carbon taxes and ESG incentives jointly affect investment timing, innovation, and the accumulation of abatement capital over time.

Third, we treat the emission measurement as exogenous and noisy, but unbiased. In practice, ESG metrics are subject to reporting discretion, measurement error, and potential manipulation. Endogenizing the information structure—by allowing the principal to invest in monitoring or verification technologies—would further enrich the analysis and could help explain cross-firm heterogeneity in the adoption of ESG-linked pay.

Fourth, we assume that the agent does not have ESG-related preferences and is indifferent with respect to emission reductions. He only provides abatement effort if he is financially compensated. We leave the introduction of ESG-preferences into the agent's utility function as a promising avenue for future research.

Finally, we focus on a single firm facing an exogenous carbon tax. General equilibrium effects, strategic interactions across firms, and political economy considerations behind carbon tax design are beyond the scope of the paper. Extending the framework to an industry setting could shed light on how ESG compensation affects competitiveness, relocation incentives, and aggregate emissions.

Despite these limitations, the model yields several implications for practice that are relevant for corporate decision-makers and policymakers. For firms and boards, the analysis underscores that ESG-linked compensation can be value-enhancing when it is aligned with the firm's underlying objectives and information environment. ESG incentives should neither be symbolic nor excessive. Contracts that place too little weight on environmental performance fail to induce meaningful abatement, while overly aggressive ESG incentives—especially in high carbon-tax environments—can distort effort allocation and undermine contract feasibility. Compensation committees should therefore calibrate ESG weights carefully, taking into account both regulatory conditions and the precision of available ESG performance measures.

For boards and managers, the results clarify the role of ESG incentives as part of a broader governance architecture. ESG-linked pay is most effective when supported by credible measurement, internal reporting systems, and operational levers that allow managers to influence emissions effectively. In such settings, ESG incentives shift managerial focus from short-run output expansion toward cleaner production processes and efficient abatement technologies.

For policymakers and regulators, the findings highlight that private governance mechanisms can complement carbon pricing—but only up to a point. Carbon taxes strengthen incentives to reduce emissions, yet they also narrow the range of contractual designs that firms can implement internally and they lower production levels. This suggests that carbon taxes may unintentionally crowd out effective ESG-based contracting and impose harmful effects on the economy. Consequently, policymakers should observe the prevalence of ESG-based contracts and other abatement actions when setting carbon tax rates.

Similarly, regulators seeking to harness private incentives should critically assess whether regulatory interventions actually produce the intended effects. A core design principle of Smart Regulation is the deployment of a mix of regulatory instruments that are ideally complementary in achieving the targeted regulatory objective. At the same time, "smorgasbordism", that is, the indiscriminate simultaneous use of all available regulatory instruments, should be avoided (Gunningham and Sinclair, 2017). In the present context, this implies that, given heterogeneous principal ESG preferences combined with carbon-tax-dependent feasibility ranges for compensation contracts, a mandatory introduction of ESG-linked compensation schemes for groups of firms cannot be recommended.[6]

More broadly, the paper cautions against evaluating carbon taxes solely based on their direct effects on production and emissions. By influencing internal incentive structures, carbon pricing shapes how firms organize, monitor, and motivate their managers. Well-designed climate policy thus interacts with corporate governance rather than operating in isolation.

Overall, our analysis suggests that effective decarbonization is most likely when public and private instruments are aligned: carbon taxes provide a clear external price signal, while ESG-linked compensation translates this signal into targeted managerial incentives. Understanding this interaction is essential for designing climate policies and corporate governance structures that achieve emission reductions without unnecessarily sacrificing economic performance.

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[6] A preliminary version of the European Union's Corporate Sustainability Due Diligence Directive (CSDDD) contained such an obligation, which was ultimately omitted from the final version (European Commission, 2022, Article 15(3)).

A Proofs

A.1 Proof of Lemmas 1 and 2

Proof. We start with Model A2 und derive Model A1 as a special case of Model A2 with $p = 0$.

In Model A2 the agent's compensation and the resulting certainty equivalent are given by:

$$\begin{aligned} w_{A2} &= vx + f && (18) \\ CE_{A2} &= (b_1 - p)\, va_1 + f - \frac{1}{2}a_1^2 - \frac{r}{2}v^2\sigma_x^2 && (19) \end{aligned}$$

Maximizing the agent's certainty equivalent with respect to productive effort a_1 yields:

$$\frac{dCE_{A2}}{da_1} = v\,(b_1 - p) - a_1 = 0 \quad \Rightarrow \quad a_1 = v\,(b_1 - p) \tag{20}$$

Substituting the optimal productive effort into the participation constraint (2) yields the fixed payment f:

$$f_{A2} = \frac{1}{2}\left[a_1^2 - 2a_1\,(b_1 - p)\,v + r\sigma_x^2 v^2\right] \tag{21}$$

Inserting this fixed payment and the optimal productive effort into the principal's payoff function makes that function only dependent on the bonus coefficient v:

$$UP_{A2} = v\,(b_1 - p)\,(b_1 - p - \alpha) - \frac{1}{2}v^2\left[(b_1 - p)^2 + r\sigma_x^2\right] \tag{22}$$

Maximizing with respect to v leads to the optimal bonus coefficient:

$$\begin{aligned} \frac{dUP_{A2}}{dv} &= (b_1 - p)\,(b_1 - p - \alpha) - v\left[(b_1 - p)^2 + r\sigma_x^2\right] = 0 \\ &\Rightarrow \quad v_{A2} = \frac{(b_1 - p)\,(b_1 - p - \alpha)}{(b_1 - p)^2 + r\sigma_x^2} && (23) \end{aligned}$$

Substituting the optimal bonus coefficient v_{A2} into the principal's payoff function and the emission function yields:

$$\begin{aligned} UP_{A2}\big|_{v=v_{A2}} &= \frac{(b_1-p)^2\,(b_1-p-\alpha)^2}{2\left[(b_1-p)^2+r\sigma_x^2\right]} && (24)\\ e_{A2}\big|_{v=v_{A2}} &= \frac{(b_1-p)^{\,2}\,(b_1-p-\alpha)}{(b_1-p)^{\,2}+r\sigma_x^2} && (25) \end{aligned}$$

The corresponding results for Model A1 are obtained for setting the carbon tax to zero $(p=0)$:

$$\begin{aligned} v_{A1} &= v_{A2}\big|_{p=0} = \frac{b_1\,(b_1-\alpha)}{b_1^2+r\sigma_x^2} && (26)\\ UP_{A1} &= UP_{A2}\big|_{p=0} = \frac{b_1^2\,(b_1-\alpha)^{\,2}}{2\,(b_1^2+r\sigma_x^2)} && (27)\\ e_{A1} &= e_{A2}\big|_{p=0} = \frac{b_1^2\,(b_1-\alpha)}{b_1^2+r\sigma_x^2} && (28) \end{aligned}$$

■

A.2 Proof of Proposition 1

Proof. The partial derivative of the bonus coefficient v_{A2} with respect to the carbon tax rate p is negative:

$$\frac{\partial v_{A2}}{\partial p} = \frac{-\alpha\,\overbrace{(b_1-p)^2}^{>0} - \overbrace{(2b_1-2p-\alpha)}^{>0}\,r\sigma_x^2}{\underbrace{\left[(p-b_1)^2+r\sigma_x^2\right]^2}_{>0}} < 0 \tag{29}$$

Zero is a lower bound for the principal's payoff function (8), because negative payoffs can be prevented by simply not employing the agent. Therefore, $b_1-p-\alpha$ and b_1-p must both be positive. Otherwise, (8) would be negative, which contradicts the lower bound of zero. Moreover, $2\,(b_1-p)-\alpha > 2\,(b_1-p-\alpha) > 0$. Consequently, the numerator of (29) is negative, whereas the denominator is positive.

The partial derivative of the principal's payoff function UP_{A2} with respect to the carbon tax rate p is negative:

$$\frac{\partial UP_{A2}}{\partial p}=\frac{-\overbrace{(b_1-p)}^{>0}\overbrace{(b_1-p-\alpha)}^{>0}\left[\overbrace{(b_1-p)^3}^{>0}+\overbrace{(2b_1-2p-\alpha)}^{>0}\overbrace{r\sigma_x^2}^{>0}\right]}{\underbrace{\left[(b_1-p)^2+r\sigma_x^2\right]^2}_{>0}}<0 \tag{30}$$

This inequality holds because $2(b_1-p)-\alpha>b_1-p-\alpha>0$ and $b_1-p>0$. Consequently, the numerator of (30) is negative, whereas the denominator is positive.

The partial derivative of the emission function e_{A2} with respect to the carbon tax rate p is negative:

$$\frac{\partial e_{A2}}{\partial p}=-\frac{\overbrace{(b_1-p)^4}^{>0}+\overbrace{(b_1-p)}^{>0}\overbrace{(3b_1-3p-2\alpha)}^{>0}\overbrace{r\sigma_x^2}^{>0}}{\underbrace{\left[(b_1-p)^2+r\sigma_x^2\right]^2}_{>0}}<0 \tag{31}$$

This is because $3(b_1-p)-2\alpha>3(b_1-p-\alpha)>0$, and $b_1-p>0$. Consequently, the numerator of (31) is negative, whereas the denominator is positive. ■

A.3 Proof of Lemma 3

Proof. In Model B1 the agent's compensation and the resulting certainty equivalent are given by:

$$w_{B1} = vx-\beta e+f \tag{32}$$

$$CE_{B_1} = b_1va_1-\beta(a_1-b_2a_2)+f-\frac{a_1^2}{2}-\frac{a_2^2}{2}-\frac{r}{2}\left(\sigma_x^2v^2+\sigma_\varepsilon^2\beta^2\right) \tag{33}$$

The partial derivatives of the agent's certainty equivalent with respect to productive effort a_1 and emission reduction effort a_2 and the resulting optimal effort levels are:

$$\frac{dCE_{B1}}{da_1} = vb_1 - \beta - a_1 = 0 \qquad \Rightarrow \qquad a_1 = vb_1 - \beta \tag{34}$$

$$\frac{dCE_{B1}}{da_2} = \beta b_2 - a_2 = 0 \qquad \Rightarrow \qquad a_2 = \beta b_2 \tag{35}$$

Substituting the optimal effort levels into the participation constraint (2) yields the fixed payment f:

$$f_{B1} = \frac{1}{2}\left[a_1^2 + a_2^2 + r\sigma_x^2 v^2 + r\sigma_\varepsilon^2 \beta^2 - 2a_1\left(b_1 v - \beta\right) - 2a_2 b_2 \beta\right] \tag{36}$$

Inserting this fixed payment and the optimal effort levels a_1 and a_2 into the principal's payoff function gives a function that only depends on the bonus coefficients v and β:

$$\begin{aligned} UP_{B1} \;=\; & \frac{1}{2}\left[2b_1^2 v - b_1^2 v^2 + 2\alpha\left(1 + b_2^2\right)\beta - 2b_1\beta\right. \\ & \left. - \left(1 + b_2^2\right)\beta^2 - 2b_1\left(\alpha - \beta\right)v - r\left(v^2\sigma_x^2 + \beta^2\sigma_\varepsilon^2\right)\right] \end{aligned} \tag{37}$$

Maximizing with respect to v and β leads to the optimal bonus coefficients:

$$\begin{aligned} \frac{\partial UP_{B1}}{\partial v} \;&=\; b_1^2 - b_1^2 v - b_1\left(\alpha - \beta\right) - vr\sigma_x^2 = 0 \\ &\Rightarrow v = \frac{b_1\left(b_1 - \alpha + \beta\right)}{b_1^2 + r\sigma_x^2} \end{aligned} \tag{38}$$

$$\begin{aligned} \frac{\partial UP_{B1}}{\partial \beta} \;&=\; \alpha\left(1 + b_2^2\right) - b_1 - \left(1 + b_2^2\right)\beta + b_1 v - r\sigma_\varepsilon^2\beta = 0 \\ &\Rightarrow \beta = \frac{\alpha\left(1 + b_2^2\right) - b_1\left(1 - v\right)}{1 + b_2^2 + r\sigma_\varepsilon^2} \end{aligned} \tag{39}$$

The interdependence of the bonus coefficients creates a system of two linear equations with two variables. The final bonus coefficients are the solution:

$$
\begin{aligned}
v_{B1} &= \frac{b_1^2 b_2^2 + b_1(b_1-\alpha) r\sigma_\varepsilon^2}{(b_1^2 + r\sigma_x^2)(b_2^2 + r\sigma_\varepsilon^2) + r\sigma_x^2} && (40)\\
\beta_{B1} &= \frac{\alpha b_1^2 b_2^2 - \left[b_1 - \alpha(1+b_2^2)\right] r\sigma_x^2}{(b_1^2 + r\sigma_x^2)(b_2^2 + r\sigma_\varepsilon^2) + r\sigma_x^2}. && (41)
\end{aligned}
$$

Substituting the optimal bonus coefficients v_{B1} and β_{B1} into the principal's payoff function and the emission function yields after some simplifications:

$$
\left.UP_{B1}\right|_{v=v_{B1};\beta=\beta_{B1}} = \frac{b_1^2 b_2^2 \left[(b_1-\alpha)^2 + \alpha^2 b_2^2\right] + \left[b_1 - \alpha\left(1+b_2^2\right)\right]^2 r\sigma_x^2 + b_1^2\left(b_1-\alpha\right)^2 r\sigma_\varepsilon^2}{2\left[\left(b_1^2 + r\sigma_x^2\right)\left(b_2^2 + r\sigma_\varepsilon^2\right) + r\sigma_x^2\right]} \tag{42}
$$

$$
\left.e_{B1}\right|_{v=v_{B1};\beta=\beta_{B1}} = \frac{b_1^2 b_2^2 \left[b_1 - \alpha\left(1+b_2^2\right)\right] + \left(1+b_2^2\right)\left[b_1 - \alpha\left(1+b_2^2\right)\right] r\sigma_x^2 + b_1^2\left(b_1-\alpha\right) r\sigma_\varepsilon^2}{\left(b_1^2 + r\sigma_x^2\right)\left(b_2^2 + r\sigma_\varepsilon^2\right) + r\sigma_x^2} \tag{43}
$$

■

A.4 Proof of Proposition 2

Proof. The difference of the principal's payoff functions $UP_{B1} - UP_{A1}$ is given by:

$$
\begin{aligned}
UP_{B1} - UP_{A1} &= \frac{b_1^2 b_2^2 \left[(b_1-\alpha)^2 + \alpha^2 b_2^2\right] + \left[b_1 - \alpha\left(1+b_2^2\right)\right]^2 r\sigma_x^2 + b_1^2\left(b_1-\alpha\right)^2 r\sigma_\varepsilon^2}{2\left[\left(b_1^2 + r\sigma_x^2\right)\left(b_2^2 + r\sigma_\varepsilon^2\right) + r\sigma_x^2\right]}\\
&\quad - \frac{b_1^2\left(b_1-\alpha\right)^2}{2\left(b_1^2 + r\sigma_x^2\right)}\\
&= \frac{\left[\alpha b_1^2 b_2^2 - \left(b_1 - \left(1+b_2^2\right)\alpha\right) r\sigma_x^2\right]^2}{2\left(b_1^2 + r\sigma_x^2\right)\left[\left(b_1^2 + r\sigma_x^2\right)\left(b_2^2 + r\sigma_\varepsilon^2\right) + r\sigma_x^2\right]} \geq 0 && (44)
\end{aligned}
$$

Since the numerator as a squared function is always non-negative and all terms in the denominator are positive, the difference is non-negative as well.

If the ESG preference parameter reaches the critical lower bound $\underline{\alpha} = \dfrac{b_1 r\sigma_x^2}{b_1^2 b_2^2 + (1+b_2^2) r\sigma_x^2}$, the payoff functions are equal:

$$\begin{aligned} UP_{B1} - UP_{A1} &= 0 \\ \alpha b_1^2 b_2^2 - \left(b_1 - \left(1 + b_2^2\right)\alpha\right) r\sigma_x^2 &= 0 \\ \alpha\left[b_1^2 b_2^2 + \left(1 + b_2^2\right) r\sigma_x^2\right] &= b_1 r\sigma_x^2 \\ \alpha &= \frac{b_1 r\sigma_x^2}{b_1^2 b_2^2 + (1 + b_2^2)\, r\sigma_x^2} = \underline{\alpha} \qquad (45) \end{aligned}$$

For all other feasible values of α the difference is strictly positive.

The difference of the emissions between Model B1 and Model A1 is given by:

$$\begin{aligned} e_{B1} - e_{A1} &= \frac{b_1^2 b_2^2\left[b_1 - \alpha\left(1 + b_2^2\right)\right]}{\left(b_1^2 + r\sigma_x^2\right)\left(b_2^2 + r\sigma_\varepsilon^2\right) + r\sigma_x^2} \\ &\quad + \frac{\left(1 + b_2^2\right)\left[b_1 - \alpha\left(1 + b_2^2\right)\right] r\sigma_x^2 + b_1^2\left(b_1 - \alpha\right) r\sigma_\varepsilon^2}{\left(b_1^2 + r\sigma_x^2\right)\left(b_2^2 + r\sigma_\varepsilon^2\right) + r\sigma_x^2} \\ &\quad - \frac{b_1^2(b_1 - \alpha)}{b_1^2 + r\sigma_x^2} \\ &= -\frac{\overbrace{\left[b_1^2 b_2^2 + \left(1 + b_2^2\right) r\sigma_x^2\right]}^{>0}\left[\alpha b_1^2 b_2^2 - \left(b_1 - \alpha\left(1 + b_2^2\right)\right) r\sigma_x^2\right]}{\underbrace{\left(b_1^2 + r\sigma_x^2\right)\left[\left(b_1^2 + r\sigma_x^2\right)\left(b_2^2 + r\sigma_\varepsilon^2\right) + r\sigma_x^2\right]}_{>0}} \qquad (46) \end{aligned}$$

Hence, the term

$$\alpha b_1^2 b_2^2 - \left[b_1 - \alpha\left(1 + b_2^2\right)\right] r\sigma_x^2 \qquad (47)$$

determines the algebraic sign of the difference. If the term is positive, then the emission difference (46) is negative, which proves the proposition:

$$\begin{aligned} \alpha b_1^2 b_2^2 - \left[b_1 - \alpha\left(1 + b_2^2\right)\right] r\sigma_x^2 &\geq 0 \\ \alpha\underbrace{\left[b_1^2 b_2^2 + \left(1 + b_2^2\right) r\sigma_x^2\right]}_{>0} &\geq b_1 r\sigma_x^2 \qquad (48) \end{aligned}$$

The left-hand side of inequality (48) is increasing in α. For the lower bound of the preference parameter $\alpha = \underline{\alpha}$ we have:

$$\underline{\alpha}\left[b_1^2 b_2^2 + \left(1+b_2^2\right) r\sigma_x^2\right] = \frac{b_1 r\sigma_x^2}{b_1^2 b_2^2 + (1+b_2^2) r\sigma_x^2}\left[b_1^2 b_2^2 + \left(1+b_2^2\right) r\sigma_x^2\right] = b_1 r\sigma_x^2$$

In this case, (48) holds with equality, for all other (i.e., larger) feasible α, the strict inequality in (48) holds. ■

A.5 Proof of Lemma 4

Proof. In Model B2 the agent's compensation and the resulting certainty equivalent are given by:

$$\begin{aligned} w_{B2} &= vx - \beta e + f && (49)\\ CE_{B_2} &= v\left(b_1 - p\right) a_1 - \beta\left(a_1 - b_2 a_2\right) + f - \frac{a_1^2}{2} - \frac{a_2^2}{2} - \frac{r}{2}\left(\sigma_x^2 v^2 + \sigma_\varepsilon^2 \beta^2\right) && (50)\end{aligned}$$

The partial derivatives of agent's certainty equivalent with respect to productive effort a_1 and emission reduction effort a_2 and the resulting optimal effort levels are:

$$\frac{dCE_{B2}}{da_1} = v\left(b_1 - p\right) - \beta - a_1 = 0 \quad \Rightarrow \quad a_1 = v\left(b_1 - p\right) - \beta \qquad (51)$$

$$\frac{dCE_{B2}}{da_2} = \beta b_2 - a_2 = 0 \quad \Rightarrow \quad a_2 = \beta b_2 \qquad (52)$$

Substituting the optimal effort levels into the participation constraint (2) yields the fixed payment f:

$$f_{B2} = \frac{1}{2}\left[a_1^2 + a_2^2 + r\sigma_x^2 v^2 + r\sigma_\varepsilon^2 \beta^2 - 2a_1\left((b_1 - p)v - \beta\right) - 2a_2 b_2 \beta\right] \qquad (53)$$

Inserting this and the optimal effort levels a_1 and a_2 into the principal's payoff function gives a function that only depends on the bonus coefficients v and β:

$$\begin{aligned} UP_{B2} &= v\left(b_1-p\right)\left(b_1-p-\alpha\right)-\frac{1}{2}v^2\left[\left(b_1-p\right)^2+r\sigma_x^2\right] && (54)\\ &\quad -\beta\left[b_1-p-\alpha\left(1+b_2^2\right)\right]-\frac{1}{2}\beta^2\left(1+b_2^2+r\sigma_\varepsilon^2\right)+v\beta\left(b_1-p\right) && (55)\end{aligned}$$

Maximizing with respect to v and β leads to the optimal bonus coefficients:

$$\begin{aligned} \frac{\partial UP_{B2}}{\partial v} &= \left(b_1-p\right)\left(b_1-p-\alpha+\beta\right)-v\left[\left(b_1-p\right)^2+r\sigma_x^2\right]=0\\ &\Rightarrow\ v=\frac{\left(b_1-p\right)\left(b_1-p-\alpha+\beta\right)}{\left(b_1-p\right)+r\sigma_x^2} && (56)\\ \frac{\partial UP_{B2}}{\partial \beta} &= -\left[b_1-p-\alpha\left(1+b_2^2\right)\right]-\left(1+b_2^2+r\sigma_\varepsilon^2\right)\beta+\left(b_1-p\right)v=0\\ &\Rightarrow\ \beta=\frac{\alpha\left(1+b_2^2\right)-\left(b_1-p\right)\left(1-v\right)}{1+b_2^2+r\sigma_\varepsilon^2} && (57)\end{aligned}$$

As in Model B1, the interdependence of the bonus coefficients creates a system of two linear equations with two variables. The solution gives the final bonus coefficients

$$\begin{aligned} v_{B2} &= \frac{\left(b_1-p\right)b_2^2+\left(b_1-p\right)\left(b_1-p-\alpha\right)r\sigma_\varepsilon^2}{\left[\left(b_1^2-p\right)+r\sigma_x^2\right]\left(b_2^2+r\sigma_\varepsilon^2\right)+r\sigma_x^2} && (58)\\ \beta_{B2} &= \frac{\left(b_1-p\right)\alpha b_2^2-\left[b_1-p-\alpha(1+b_2^2)\right]r\sigma_x^2}{\left[\left(b_1^2-p\right)+r\sigma_x^2\right]\left(b_2^2+r\sigma_\varepsilon^2\right)+r\sigma_x^2}. && (59)\end{aligned}$$

Substituting the optimal bonus coefficients v_{B2} and β_{B2} into the principal's payoff function and the emission function yields after some simplifications:

$$\begin{aligned}
UP_{B2}|_{v=v_{B2};\beta=\beta_{B2}} &= \frac{(b_1-p)^2 b_2^2 \left[(b_1-p-\alpha)^2+\alpha^2 b_2^2\right] + \left[b_1-p-\alpha\left(1+b_2^2\right)\right]^2 r\sigma_x^2}{2\left[\left(b_1^2+r\sigma_x^2\right)\left(b_2^2+r\sigma_\varepsilon^2\right)+r\sigma_x^2\right]} \\
&\quad + \frac{(b_1-p)^2 (b_1-p-\alpha)^2 r\sigma_\varepsilon^2}{2\left[\left(b_1^2+r\sigma_x^2\right)\left(b_2^2+r\sigma_\varepsilon^2\right)+r\sigma_x^2\right]} && (60) \\
e_{B2}|_{v=v_{B2};\beta=\beta_{B2}} &= \frac{(b_1-p)^2 b_2^2 \left[b_1-p-\alpha\left(1+b_2^2\right)\right] + \left(1+b_2^2\right)\left[b_1-p-\alpha\left(1+b_2^2\right)\right] r\sigma_x^2}{\left(b_1^2+r\sigma_x^2\right)\left(b_2^2+r\sigma_\varepsilon^2\right)+r\sigma_x^2} \\
&\quad + \frac{(b_1-p)^2 (b_1-p-\alpha) r\sigma_\varepsilon^2}{\left(b_1^2+r\sigma_x^2\right)\left(b_2^2+r\sigma_\varepsilon^2\right)+r\sigma_x^2} && (61)
\end{aligned}$$

■

The corresponding results for Model B1 as derived in subsection A.3 are obtained for setting the carbon tax to zero ($p = 0$).

A.6 Proof of Proposition 3

Proof. The critical lower bound for α in Model B2 and its first and second partial derivatives with respect to the carbon tax rate are given by

$$\begin{aligned}
\underline{\alpha}' &= \frac{(b_1-p)r\sigma_x^2}{(b_1-p)^2 b_2^2+(1+b_2^2)r\sigma_x^2} > 0 \\
\frac{\partial \underline{\alpha}'}{\partial p} &= \frac{\left[(b_1-p)^2 b_2^2-\left(1+b_2^2\right)r\sigma_x^2\right] r\sigma_x^2}{\left[(b_1-p)^2 b_2^2+(1+b_2^2)r\sigma_x^2\right]^2} && (62) \\
\frac{\partial^2 \underline{\alpha}'}{\partial p^2} &= \frac{2(b_1-p)b_2^2 r\sigma_x^2 \left[(b_1-p)^2 b_2^2 - 3\left(1+b_2^2\right)r\sigma_x^2\right]}{\left[(b_1-p)^2 b_2^2+(1+b_2^2)r\sigma_x^2\right]^3} && (63)
\end{aligned}$$

Thus,

$$\frac{\partial \underline{\alpha}'}{\partial p}\left\{\begin{array}{c} > \\ = \\ < \end{array}\right\} 0 \quad \Leftrightarrow \quad (b_1 - p)^2 \left\{\begin{array}{c} > \\ = \\ < \end{array}\right\} \frac{1 + b_2^2}{b_2^2} r\sigma_x^2 \quad \Rightarrow \quad p^o \left\{\begin{array}{c} > \\ = \\ < \end{array}\right\} b_1 - \frac{\sqrt{\left(1 + b_2^2\right) r\sigma_x^2}}{b_2} \tag{64}$$

$$\frac{\partial^2 \underline{\alpha}'}{\partial p^2}\left\{\begin{array}{c} > \\ = \\ < \end{array}\right\} 0 \quad \Leftrightarrow \quad (b_1 - p)^2 \left\{\begin{array}{c} > \\ = \\ < \end{array}\right\} 3\frac{1 + b_2^2}{b_2^2} r\sigma_x^2 \quad \Rightarrow \quad p^{oo} \left\{\begin{array}{c} > \\ = \\ < \end{array}\right\} b_1 - \frac{\sqrt{3\left(1 + b_2^2\right) r\sigma_x^2}}{b_2} < p^o \tag{65}$$

The inflection point p^{oo} is smaller than the extreme point p^o, so that $\underline{\alpha}'$ is concave in $p = p^o$ and p^o is a maximum with

$$\underline{\alpha}'\left(p^o\right) = \frac{1}{2b_2}\sqrt{\frac{r\sigma_x^2}{1 + b_2^2}} \tag{66}$$

The derivative of the critical upper bound for α with respect to p in Model B2 is always negative:

$$\begin{aligned} \overline{\alpha'} &= (b_1 - p)\left(1 + \frac{b_2^2}{r\sigma_\varepsilon^2}\right) \\ \frac{\partial \overline{\alpha'}}{\partial p} &= -\left(1 + \frac{b_2^2}{r\sigma_\varepsilon^2}\right) < 0 \end{aligned} \tag{67}$$

For $\frac{\partial \underline{\alpha}'}{\partial p} \geq 0$, the interval width of feasible ESG preference parameters would obviously be decreasing in p. However, $\frac{\partial \underline{\alpha}'}{\partial p}$ can be negative, especially for small values of b_2. For the combined effect, we need the interval width of feasible α in Model B2 that is given by:

$$\overline{\alpha'} - \underline{\alpha}' = \frac{(b_1 - p)\, b_2^2 \left\{\left[(b_1 - p)^2 + r\sigma_x^2\right]\left(b_2^2 + r\sigma_\varepsilon^2\right) + r\sigma_x^2\right\}}{\left[(b_1 - p)^2 b_2^2 + \left(1 + b_2^2\right) r\sigma_x^2\right] r\sigma_\varepsilon^2} \geq 0 \tag{68}$$

The corresponding interval for model B1 can be derived from (68) for $p = 0$:

$$\left.\overline{\alpha'} - \underline{\alpha'}\right|_{p=0} = \overline{\alpha} - \underline{\alpha} = \frac{b_1 b_2^2 \left[\left(b_1^2 + r\sigma_x^2\right)\left(b_2^2 + r\sigma_\varepsilon^2\right) + r\sigma_x^2\right]}{\left[b_1^2 b_2^2 + \left(1 + b_2^2\right) r\sigma_x^2\right] r\sigma_\varepsilon^2} > 0 \tag{69}$$

Hence, the interval $\left[\underline{\alpha'}; \overline{\alpha'}\right]$ is non-empty for $b_1 > p$. The partial derivative of the interval width with respect to the carbon tax is

$$\frac{\partial\left(\overline{\alpha'} - \underline{\alpha'}\right)}{\partial p} = \underbrace{\frac{-b_2^2}{\left[(b_1 - p)^2 b_2^2 + (1 + b_2^2) r\sigma_x^2\right]^2 r\sigma_\varepsilon^2}}_{<0} \cdot z < 0 \tag{70}$$

with

$$\begin{aligned} z \quad = \quad & \overbrace{\left[3\sigma_\varepsilon^2 \left(b_1 - p\right)^2 + \sigma_x^2 \left(1 + r\sigma_\varepsilon^2\right)\right]}^{>0} \overbrace{r^2\sigma_x^2}^{>0} + \overbrace{b_2^4 \left[\left(b_1 - p\right)^2 + r\sigma_x^2\right]^2}^{>0} \\ & + \underbrace{b_2^2 r}_{>0} \underbrace{\left[\left(b_1 - p\right)^2 + r\sigma_x^2\right]}_{>0} \underbrace{\left[\sigma_\varepsilon^2 \left(\left(b_1 - p\right)^2 + r\sigma_x^2\right) + 2\sigma_x^2\right]}_{>0} > 0 \end{aligned}$$

Hence, the width of the interval $\left[\underline{\alpha'}; \overline{\alpha'}\right]$ decreases in the carbon tax rate. ■

A.7 Proof of Proposition 4

Proof. The difference of the principal's payoff function $UP_{B2} - UP_{A2}$ is given by:

$$\begin{aligned} UP_{B2} - UP_{A2} \quad = \quad & \frac{\left(b_1 - p\right)^2 b_2^2 \left[\left(b_1 - p - \alpha\right)^2 + \alpha^2 b_2^2\right] + \left[b_1 - p - \alpha\left(1 + b_2^2\right)\right]^2 r\sigma_x^2}{2\left[\left(b_1^2 + r\sigma_x^2\right)\left(b_2^2 + r\sigma_\varepsilon^2\right) + r\sigma_x^2\right]} \\ & + \frac{\left(b_1 - p\right)^2 \left(b_1 - p - \alpha\right)^2 r\sigma_\varepsilon^2}{2\left[\left(b_1^2 + r\sigma_x^2\right)\left(b_2^2 + r\sigma_\varepsilon^2\right) + r\sigma_x^2\right]} - \frac{\left(b_1 - p\right)^2 \left(b_1 - p - \alpha\right)^2}{2\left[\left(b_1 - p\right)^2 + r\sigma_x^2\right]} \\ = \quad & \frac{\left[\alpha b_2^2 \left(b_1 - p\right)^2 - \left(b_1 - p - \alpha\left(1 + b_2^2\right)\right) r\sigma_x^2\right]^2}{2\left[\left(b_1 - p\right)^2 + r\sigma_x^2\right]\left[\left(\left(b_1 - p\right)^2 + r\sigma_x^2\right)\left(b_2^2 + r\sigma_\varepsilon^2\right) + r\sigma_x^2\right]} \geq 0 \end{aligned} \tag{71}$$

Since the numerator as a squared function is always non-negative and all terms in the denominator are positive, the difference is non-negative as well.

If the ESG preference parameter reaches the critical lower bound $\alpha = \underline{\alpha'}$, the payoff functions are equal:

$$\begin{aligned}
UP_{B2} - UP_{A2} &= 0 \\
\alpha b_2^2 \left(b_1 - p\right)^2 - \left(b_1 - p - \alpha\left(1 + b_2^2\right)\right) r\sigma_x^2 &= 0 \\
\alpha\left[\left(b_1 - p\right)^2 b_2^2 + \left(1 + b_2^2\right) r\sigma_x^2\right] &= \left(b_1 - p\right) r\sigma_x^2 \\
\alpha = \frac{\left(b_1 - p\right) r\sigma_x^2}{\left(b_1 - p\right)^2 b_2^2 + \left(1 + b_2^2\right) r\sigma_x^2} &= \underline{\alpha'} \qquad (72)
\end{aligned}$$

For all other feasible values of α the difference is strictly positive.

The difference of emissions between Model B2 and Model A2 is

$$\begin{aligned}
e_{B2} - e_{A2} &= \frac{\left(b_1 - p\right)^2 b_2^2 \left[b_1 - p - \alpha\left(1 + b_2^2\right)\right] + \left(1 + b_2^2\right)\left[b_1 - p - \alpha\left(1 + b_2^2\right)\right] r\sigma_x^2}{\left(b_1^2 + r\sigma_x^2\right)\left(b_2^2 + r\sigma_\varepsilon^2\right) + r\sigma_x^2} \\
&\quad + \frac{\left(b_1 - p\right)^2 \left(b_1 - p - \alpha\right) r\sigma_\varepsilon^2}{\left(b_1^2 + r\sigma_x^2\right)\left(b_2^2 + r\sigma_\varepsilon^2\right) + r\sigma_x^2} \\
&\quad - \frac{\left(b_1 - p\right)^2 \left(b_1 - p - \alpha\right)}{\left(b_1 - p\right)^2 + r\sigma_x^2} \\
&= -\frac{\overbrace{\left[\left(b_1 - p\right)^2 b_2^2 + \left(1 + b_2^2\right) r\sigma_x^2\right]}^{>0}\left[\alpha\left(b_1 - p\right)^2 b_2^2 - \left(b_1 - p - \alpha\left(1 + b_2^2\right)\right) r\sigma_x^2\right]}{\underbrace{\left[\left(b_1 - p\right)^2 + r\sigma_x^2\right]\left[\left(\left(b_1 - p\right)^2 + r\sigma_x^2\right)\left(b_2^2 + r\sigma_\varepsilon^2\right) + r\sigma_x^2\right]}_{>0}}
\end{aligned} \qquad (73)$$

Similar to the proof of Proposition 2, the term

$$\alpha\left(b_1 - p\right)^2 b_2^2 - \left(b_1 - p - \alpha\left(1 + b_2^2\right)\right) r\sigma_x^2$$

determines the algebraic sign of the emission difference. If this term is positive, then the emission difference (73) is negative, which proves the proposition:

$$\alpha \underbrace{\left[\left(b_1 - p\right)^2 b_2^2 + \left(1 + b_2^2\right) r\sigma_x^2\right]}_{>0} - \left(b_1 - p\right) r\sigma_x^2 \geq 0 \qquad (74)$$

The first term in (74) increases in α. For the lower bound of the preference parameter $\alpha = \underline{\alpha}'$, (74) holds with equality:

$$\begin{aligned} & \underline{\alpha}' \left[(b_1 - p)^2 b_2^2 + \left(1 + b_2^2\right) r\sigma_x^2 \right] \\ = \; & \frac{(b_1 - p) r\sigma_x^2}{(b_1 - p)^2 b_2^2 + (1 + b_2^2) r\sigma_x^2} \left[(b_1 - p)^2 b_2^2 + \left(1 + b_2^2\right) r\sigma_x^2 \right] = (b_1 - p)\, r\sigma_x^2, \end{aligned}$$

for all other (i.e., larger) feasible values of α, (74) holds with strict inequality. ■

A.8 Proof of Proposition 5

Proof. The partial derivative of the emission function e_{B2} with respect to the carbon tax rate p is given by:

$$\begin{aligned} \frac{\partial e_{B2}}{\partial p} = \; & -\frac{1}{\underbrace{\left[\left((b_1 - p)^2 + r\sigma_x^2 \right) \left(b_2^2 + r\sigma_\varepsilon^2 \right) + r\sigma_x^2 \right]^2}_{>0}} \\ & \cdot \left[\overbrace{(b_1 - p)^4 \left(b_2^2 + r\sigma_\varepsilon^2 \right)^2}^{>0} + \overbrace{(b_1 - p)^2 \left(2b_2^4 + 2b_2^2 + 5b_2^2 r\sigma_\varepsilon^2 + 2r\sigma_\varepsilon^2 \right) r\sigma_x^2}^{>0} \right. \\ & \left. + \underbrace{(b_1 - p)(3b_1 - 3p - 2\alpha)\, r^3 \sigma_x^2 \sigma_\varepsilon^4}_{>0} + \underbrace{\left(1 + b_2^2\right) \left(1 + b_2^2 + r\sigma_2^2\right) r^2 \sigma_x^4}_{>0} \right] < 0 \qquad (75) \end{aligned}$$

Similar to the proof of Proposition 1 this is because $3(b_1 - p) - 2\alpha > 3(b_1 - p - \alpha) > 0$, and $b_1 - p > 0$. Consequently, the term $(b_1 - p)(3b_1 - 3p - 2\alpha)\, r^3 \sigma_1^2 \sigma_2^4$ in (75) is positive, so that the partial derivative $\frac{\partial e_{B2}}{\partial p}$ is negative.

The partial derivative of the principal's payoff function UP_{B2} with respect to the carbon tax rate $\frac{\partial UP_{B2}}{\partial p}$ may take either algebraic sign. To prove this, it is sufficient to show the existence of at least one numerical example for a positive and a negative partial derivative. This numerical example is provided in Figure 2 where $\frac{\partial UP_{B2}}{\partial p} < 0$ for smaller values of p and $\frac{\partial UP_{B2}}{\partial p} > 0$ for sufficiently large levels of p. ■

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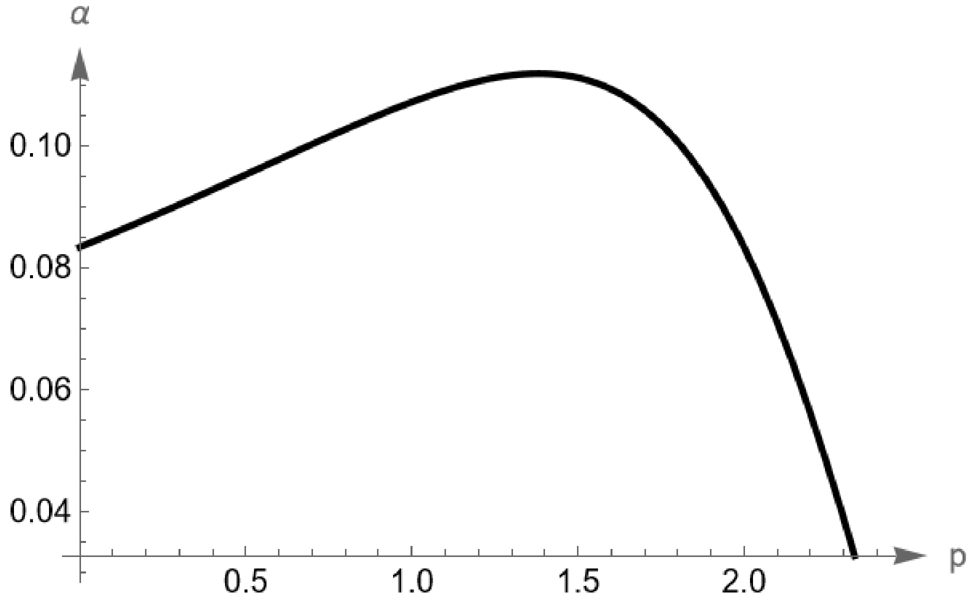

Figure 1: Lower feasibility bound for the principal's ESG preferences $\underline{\alpha}'$ in Model B2. Parameter values: $b_1 = 2.5, b_2 = 2, \sigma_x = 1, \sigma_\varepsilon = 1, r = 1$

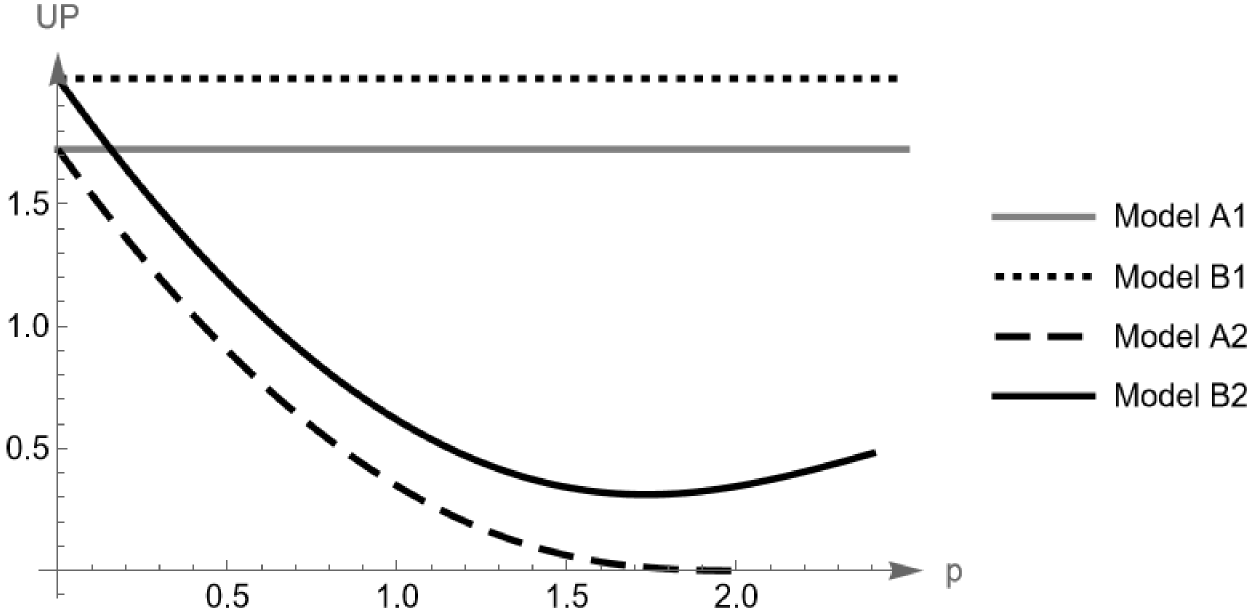

Figure 2: Principal's Payoff in Model A1 (grey solid), A2 (black dashed), B1 (black dotted), and B2 (black solid). Parameter values: $b_1 = 2.5, b_2 = 2, \sigma_x = 1, \sigma_\varepsilon = 1, r = 1, \alpha = 0.5$

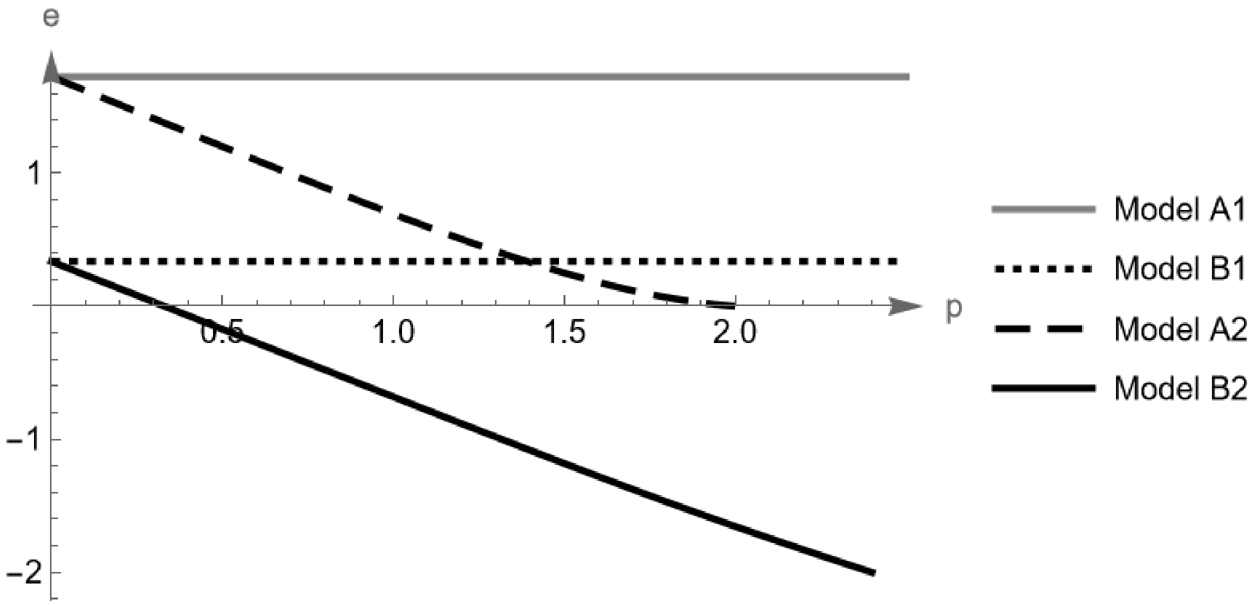

Figure 3: Emissions in Model A1 (grey solid), A2 (black dashed), B1 (black dotted), and B2 (black solid). Parameter values: $b_1 = 2.5, b_2 = 2, \sigma_x = 1, \sigma_\varepsilon = 1, r = 1, \alpha = 0.5$

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