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On the design of managerial incentives for sustainability investments in the presence of competitors

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In many industries, an increasing number of firm owners tie managers' incentives to sustainability investments. *Positive rewards* directly increase a manager's total pay when that manager makes sustainability investments, whereas *negative rewards* directly decrease a manager's pay when those investments are made. Strategic incentive design literature posits that such organizational choices also affect the decisions of a firm's competitors. This paper uses a game-theoretic framework to analyze the effects of sustainability incentives in a setting with two competing firms. In contrast to the existing literature, in the current paper sustainability investments have a demand-enhancing effect and can increase or decrease the unit cost of production, making the current framework more in line with industrial practice. The results show that a firm invests in sustainability only if the demand-enhancing effects outweigh the cost-increasing effects. More importantly, positively rewarding managers for sustainability investments is done in equilibrium only if the innovation capability of the firm is sufficiently high. However, in terms of profits, those positive rewards lead to a prisoner's dilemma. When innovation capability is lower, firm owners use negative rewards and raise their profits. Another finding is that rival firms that cooperate in determining their sustainability incentives increase their profits but do so using negative rewards. These results, which have not been reported in the literature, point to some critical trade-offs in terms of sustainability investments and firm profits when sustainability incentives are considered and are both managerially and academically relevant.

1. Introduction

Firms' sustainability practices aim to reduce environmental impacts and improve social well-being in a profitable way. Adopting more sustainable practices is becoming increasingly imperative for firms and has been shown to be a source of competitive advantage and positive financial, environmental, and social performance (Bonifant et al., 1995; Epstein et al., 2015; Kleindorfer et al., 2005). Firms can become more sustainable as a result or by-product of regular management practices such as quality management, but often significant investments are required in terms of product or process innovation. Consequently, most firms direct at least some of their R&D investment budgets towards sustainability (Iyer and Soberman, 2016). In this paper, the focus is on the provision of managerial incentives for sustainability investments (i.e., "sustainability incentives"). Sustainability incentives are defined as the financial instruments a firm owner uses to influence the decisions of the manager, in particular sustainability investments. Managers obtain a positive reward if their sustainability investments directly *increase* their total pay, while negative rewards *decrease* total pay when managers make sustainability investments. In effect, the anticipation of positive (negative) rewards encourage (discourage) company managers to invest in sustainability. Many firms are incorporating sustainability into their incentive schemes. Intel is one of the first major firms to link environmental metrics to employee pay, while a study carried out by Ceres in 2014 revealed that 24% of the surveyed companies tied executive pay to sustainability metrics (The Guardian, 2014).

However, are sustainability incentives justified from a competitive perspective? This paper argues that the provision of such incentives critically revolves around three main factors. First, it is important to consider the demand-enhancing effect of sustainability investments. Indeed, strong empirical evidence indicates that many consumers are willing to pay a price premium for a broad range of sustainable products (e.g., Carvalho et al., 2017). Second, it is important to study the effect of a product's ultimate sustainability level (determined by investments) on the unit cost of

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production. Sustainable products are often costlier to produce. Fair wages, increased worker safety, more living space for farm animals, reduced yield of crops due to organic farming, all contribute to higher production costs. In industrial settings, investments are often needed to improve energy efficiency or water treatment; however it is questionable whether these investments will pay off financially. Indeed, according to Wu and Pagell (2011, p. 577), “not all environmental practices will bring cost savings and some will increase costs, especially in the short term. For instance, proactive investments in green technology may not pay off for decades.” At the same time, several companies manage to *reduce* their cost as a result of sustainability measures. PepsiCo, for example, saved hundreds of millions of dollars since 2010 due to its reduction of water, energy, waste, and packaging. Third, empirical evidence in the strategic incentive design literature (e.g., Fershtman and Judd, 1987) shows that rival firms respond to each other's strategic decisions, such as incentive provision. A firm owner's sustainability incentives and their effect on a manager's sustainability investments are therefore likely to affect a competitor's decisions. While strategic incentive design theory has been applied to sustainability incentives, this paper is the first to study the aforementioned three factors in conjunction, using a two-stage game-theoretic model. In the model, the strategic nature of sustainability incentives resides in both stages. In the first stage, two firm owners independently set the incentive parameters. Each owner determines whether its manager is rewarded positively or negatively when making sustainability investments, and each anticipates the decision of the rival owner. In the second stage, the managers become aware of each other's incentives and take these into account when investing in sustainability and competing in the product market.

This study addresses the following questions: *When do firm owners prefer positive versus negative rewards to encourage or discourage their managers to make sustainability investments in a competitive context? What is the effect of these rewards on equilibrium outcomes such as sustainability investments and profits?* An important risk in the strategic interaction between firms is collusion (Dai et al., 2017; Schinkel and Spiegel, 2017). It is known that some types of cooperation between firms may lead to adverse effects such as lower levels of investment. Therefore, another question in this study is the following: *Will cooperating firm owners use positive or negative rewards?* The answers to these questions are relevant from both theoretical and practical points of view. Theoretically, while other papers in this domain find that in equilibrium, rewards for making sustainability investments are negative, this paper shows the circumstances under which rewards are positive. This result helps demonstrate that using positive (negative) rewards has a positive (negative) effect on sustainability investments but a negative (positive) effect on firm profits. Importantly, this paper also finds that cooperating firm owners will discourage investments by using negative rewards. Managers and policy makers will also find the results useful, as a more detailed picture is drawn to show the best provision of incentives in a competitive (and cooperative) context.

The structure of this article proceeds as follows. Section 2 provides a literature review and clarifies the positioning of the paper. Section 3 describes the model framework. Results appear in Section 4. More specifically, Section 4 describes the results when profit maximization incentives and sustainability incentives are used and compares these cases. Moreover this section discusses what happens when firm owners can cooperate in determining compensation parameters. Finally, the robustness of the model is analyzed when the mode of competition relies on quantities rather than prices. The final section (Section 5) elaborates on the conclusions of the study and discusses the implications and directions for future research.

2. Literature review

The body of empirical literature on rewarding executives or managers for sustainability investments is growing (e.g., Berrone and Gomez-Mejia, 2009; Gangi and Varrone, 2018; García-Sánchez et al., 2019; Moretto et al., 2018). The current paper takes a modeling perspective and integrates analytical research on strategic sustainability investments with the literature on strategic incentive design. The former stream has mainly followed game-theoretic approaches. In this stream, sustainability investments may reduce environmental impacts (Delmas and Pekovic, 2015; Feichtinger et al., 2016; Lambertini et al., 2017; Yenipazarli, 2017), increase consumers' willingness to pay (Dai et al., 2017; Liu et al., 2012; Schinkel and Spiegel, 2017), or both (Luo et al., 2016; Yang and Chen, 2018). Sustainable investment models can also be categorized according to the effect on the unit cost of production. In their framework, Liu et al. (2012) assume a (quadratic) increase of the unit cost due to an increase of sustainability levels of the product (i.e., eco-friendliness), while in Hammami et al. (2018), the unit cost of production increases due to emission intensity reduction. In contrast, other papers assume that sustainability may decrease unit cost (Lambertini et al., 2017; Yang and Chen, 2018; Yenipazarli, 2017), driven, for example, by the notion that sustainability investments can improve eco-efficiency. In other papers, the introduction of sustainability practices is assumed to have no effect on unit cost at all (e.g., Dai et al., 2017). The framework in the current paper incorporates consumers' willingness to pay and allows the cost of production to increase or decrease as a result of manufacturing more sustainable products.

Strategic incentive design questions the effects of incentive distortions in the owner–manager relationship on rival firm behavior. In these models, it is generally assumed that profit-maximizing owners may prefer to delegate decision rights to managers and incentivize these managers with financial rewards for sales achievements, cost reductions, or quality improvements (e.g. Balasubramanian and Bhardwaj, 2004; Fershtman and Judd, 1987; Sklivas, 1987; Veldman and Gaalman, 2015). Such owner–manager settings are frequently referred to as strategic delegation, which is “a strategic tool that enables external commitments that cannot be credibly made without delegation of decision making to another, typically subordinate decision maker” (Sengul et al., 2012, p. 376). Typically, if a profit-maximizing owner instructs the manager to maximize some function other than pure profits, this is viewed as an incentive distortion. The effect of such a distortion in a strategic context is that rival owner–manager pairs respond to the incentives used within a firm. For example, Veldman et al. (2014) demonstrate that if one manager invests more in cost-reducing R&D because the manager is positively rewarded for cost reduction, then the competitor's manager will invest less in response because of this incentive distortion. However, for the incentive parameters to have a strategic effect, they should be credible, irreversible, and observable—conditions that can be incorporated in game-theoretic frameworks, but are also in line with practice. As Sengul et al. (2012) mention in a literature review, strategic incentive design models often predict that the use of strategic incentives by an individual firm benefits that firm because of more aggressive investments made by managers. Yet in industries in which all firms have adopted strategic incentives, profits often suffer and a prisoner's dilemma may occur. This paper demonstrates that this is indeed the case.

To the best of our knowledge, there are three papers that have applied the strategic incentive design framework to decisions (e.g., investments) in the realm of sustainability. Bian et al. (2016) consider sustainability incentives based on consumer surplus and show when equilibrium incentives are positive in quantity and price competition regimes, and discuss the various effects of those. Lambertini and Tampieri (2015) model an oligopolistic product market in which one firm is driven by a corporate social responsibility (CSR) goal. This goal is modeled using a managerial objective function that consists of firm profits, consumer surplus, and pollution externalities. In line with the premises of strategic incentive design, they show that the firm that is driven by CSR may even be more profitable than competitors. Closest to the model presented in this paper is that given in Dobson and Chakraborty (2018), who study managerial incentives for (cost-reducing) sustainability efforts in a context of Cournot complementary monopoly.[1] They find that firm owners will offer their managers negative rewards for their sustainability investments if the owners of the two (complementary) producers independently determine the incentive parameters. In Cournot complementary monopoly, the complementary producers are incentivized to keep component prices artificially high; as a result, firm owners will never stimulate their managers to reduce costs (which would lead to lower component prices). However, Dobson and Chakraborty (2018) only focus on the cost-reducing effects of investments and ignore any demand-enhancing effects. Using both a general demand model that includes a product's sustainability level (determined by an investment) and the different unit cost effects of sustainability investment, the current paper finds that positive rewards linked to sustainability investments (determined competitively and independently by firm owners) are used in equilibrium under certain conditions.

An important related question in the context of strategic investment concerns the role of cooperation between competitors. Papers such as d'Aspremont and Jacquemin (1988) have shown that whether or not cooperation raises investments depends on a variety of factors. In the sustainability domain, both vertical and horizontal cooperation have been analyzed. Dai et al. (2017) and Yenipazarli (2017) study cooperation between an upstream supplier and a downstream retailer. Horizontal cooperation, which is examined in the current paper, has been addressed in Schinkel and Spiegel (2017) and Dobson and Chakraborty (2018). Schinkel and Spiegel (2017) analyze cooperation between two competitors in a game where a quantity competition stage follows a sustainability investment stage in which the competitors coordinate their investment. They find that such cooperation lowers investment levels and harms consumers. Only Dobson and Chakraborty (2018) have addressed horizontal cooperation within a strategic incentive design model. They find that cooperation between firm owners in the incentive determination stage results in the use of positive rewards and increased investment levels, whereas negative rewards are never used. The current paper shows, however, that cooperation between firm owners in determining incentive parameters leads to the use of negative rewards only. That is, a manager is discouraged from making those investments because they *reduce* the manager's pay. This is a novel finding that contrasts with the extant literature.

To summarize, other papers in this domain have studied managerial incentives based on consumer surplus, pollution externalities, and cost reduction. None has considered demand models in which consumers may have a willingness to pay for sustainable products, nor have these papers linked a product's sustainability level to investments for which a manager could be rewarded. Finally, research to date has neglected that manufacturing a sustainable product can either increase or decrease the unit cost of production, and that this difference should be studied. The current paper addresses these gaps in the literature. Specifically, this paper is the first to study the strategic sustainability incentives linked to a manager's investments into a product's sustainability level, in a setting in which sustainability levels affect the unit cost of production, increase consumers' willingness to pay or both.

3. The model

This paper centers on the sustainability incentives profit-maximizing firm owners give to managers, and the effects of such incentive distortions on sustainability investments and firm profits in a competitive context. A game-theoretic framework has been set up to study the research questions. Game theory studies strategic interactions between decision makers, and, given these interactions, describes the best course of action. In the context of this study, game theory is used to isolate the effects of strategic decision variables (product prices, sustainability levels, monetary incentive weights) on outcomes (e.g., profits), and the effect of sustainability incentives on investments in a product's sustainability level. In addition, the effect of cooperation in the incentive determination stage on incentives and sustainability levels can be analyzed. Game theory is the framework of choice in strategic incentive design literature (Sengul et al., 2012), and the results of formal game-theoretic models can be tested empirically in subsequent research.

In the model, firm owners may commit to sustainability by incentivizing their managers; in doing so firm owners could alter the nature of interfirm competition. To be able to study the strategic impact of sustainability incentives, this paper follows the standard framework in the strategic incentive design literature and assumes that the incentive weights determined by firm owners are public knowledge. This assumption is natural, as many firms are required to display the details of their managers' pay in yearly reports. This may particularly hold true in the case of positive rewards, as presenting such information to the outside world could be beneficial for the firm's public image. Indeed, firm owners may *want* those details to become publicly known because of their strategic effect.

These characteristics are implemented into a two-stage game with two firms, each consisting of a profit-maximizing owner that delegates decision responsibility to an operations manager. In the first stage, the owners decide on the details of their manager's incentives. Specifically, they select the monetary incentive weight attached to a manager's sustainability investments that determines whether a manager will obtain a positive or negative reward if investments are made in the second stage (zero incentives being part of the potential set of incentive weights). As mentioned in the introduction, a manager may end up with a positive reward if sustainability investments *increase* the manager's total pay, whereas negative rewards work in the opposite way. In the second stage, the rival managers become aware of each other's incentives (i.e., the size and sign of the incentive weights); based on this knowledge they then compete in the product market by (1) making sustainability investments in a product's sustainability level and (2) selecting a product price. The subgame perfect Nash equilibrium is obtained via backward induction. The model's parameters are common knowledge for the players. The notation used in the model appears in Table 1.

The two firms compete based on a demand model that is derived from Liu et al. (2012). The demand for two competing sustainable products depends on product prices and sustainability

[1] In Cournot complementary monopoly, suppliers of the components of a composite good competitively determine their output prices, affecting the demand for the composite good manufactured by a monopolist.

Table 1
Model notation.

Notation	Description
Parameters	
A	A firm's base demand
τ	The sensitivity of a firm's demand with respect to differences in sustainability levels
k	The sensitivity of a firm's demand with respect to differences in product substitutability
γ	A firm's innovation capability
c	Constant marginal cost of production
β	Parameter indicating whether a sustainable product is cheaper ($\beta > 0$) or more expensive ($\beta < 0$) to produce than a regular one
θ	Auxiliary parameter, given by $\theta = \beta + \tau$
Variables	
I_i	Sustainability investment cost incurred by firm i, given by $I_i = \frac{1}{2}\gamma e_i^2$
$C_i(e_i)$	Unit cost of the product, given by $C_i(e_i) = c - \beta e_i$
q_i	Demand of firm i
π_i	Profit of firm i
S_i	Salary function of the manager of firm i
Π	Joint profits, given by $\Pi = \pi_1 + \pi_2$
Decision variables	
e_i	[ustainability level chosen by the decision maker of firm i
p_i	Product price level chosen by the decision maker of firm i
y_i	Auxiliary variable, given by $y_i = p_i - \tau e_i$
λ_i	The monetary incentive weight attached to each unit e_i chosen. A weight $\lambda_i > 0$ encourages investment and leads to a positive reward for any $e_i > 0$; A weight $\lambda_i < 0$ discourages investment and leads to a negative reward for any $e_i > 0$
Other notation	
i, j	Subscripts used to indicate firms, i.e., $i = 1, 2$, $j = 3 - i$
p, l	Subscripts used to indicate case at hand: the profit maximization case and sustainability incentives case, respectively

levels. Firm i's demand can be written as

$$q_i = a + \tau(e_i - k(e_j - e_i)) + k\left(p_j - p_i\right) - p_i, \tag{1}$$

where $i = 1, 2$ and $j = 3 - i$. In this model, the decision maker of firm i selects a product price p_i and sustainability level e_i, anticipating the decisions made by the rival firm j. In this demand model, the parameter $a > 0$ is a firm's base demand, while the parameters $\tau > 0$ and $k > 0$ represent the sensitivity of a firm's demand with respect to differences in sustainability levels and substitutability, respectively. An important advantage of this model is that total demand $Q = q_1 + q_2$ is affected by the chosen price and sustainability levels, but not by substitutability. Note that in a market without substitutability, one would have $k = 0$, which reduces the firms to monopolists in their respective markets. Because the primary focus of this paper is on the strategic interaction between firms, the assumption is that $k > 0$. Finally, if $\tau > 1$, demand is more sensitive to sustainability compared to price.

A firm would bear an investment cost for its sustainability investments $I_i = 0.5\gamma e_i^2$, which reflects diminishing marginal returns to R&D efforts. This is a common way of modeling R&D investments in sustainable products and processes (e.g. Dai et al., 2017; Iyer and Soberman, 2016; Nielsen et al., 2019; Yenipazarli, 2017; Hong and Guo, 2019) and suggests that budgets may be limited while obtaining certain benefits (given a fixed budget) is becoming increasingly difficult after picking the "low-hanging fruit". In addition, the parameter $\gamma > 0$ denotes a firm's given innovation capability; the higher γ, the lower is a firm's innovation capability of making sustainability investments. Note that throughout the paper, γ is an industry-specific parameter. This is not an unreasonable assumption, as many industries can be characterized in terms of their R&D maturity.

The unit cost of a single sustainable product depends on a constant marginal cost of production c and the sustainability level of the product. Unit cost is written as $C_i(e_i) = c - \beta e_i$. Importantly, if $\beta > 0$, a sustainable product is cheaper to produce than a unsustainable product. This would apply, for instance, when a firm's investments yield an innovative way of reusing waste streams that otherwise would have to be disposed of (possibly at a high cost). If $\beta < 0$, a sustainable product costs more to produce than a conventional one. Finally, it is necessary to set $a - c > 0$, which is a natural assumption to ensure that the market is large enough for the firms to sell a strictly positive number of products at strictly positive product prices.

Firm profits can be written as

$$\pi_i = (p_i - c + \beta e_i)q_i - \frac{1}{2}\gamma e_i^2. \tag{2}$$

Interestingly, the demand function in (1) can be rewritten as

$$q_i = a - (k+1)y_i + ky_j,$$

where $y_i = p_i - \tau e_i$. Substituting this into the profit function yields

$$\pi_i = (y_i - c + (\beta + \tau)e_i)q_i - \frac{1}{2}\gamma e_i^2.$$

The number of parameters in the profit function can now be reduced by letting $\theta = \beta + \tau$. Note that $\theta > \beta$ always, as $\tau > 0$. Clearly, maximizing this profit function with respect to y_i and e_i is similar to maximizing (2) with respect to p_i and e_i. In addition, consumer prices in equilibrium can be easily obtained as $p_i = y_i + \tau e_i$.

In the model, sustainability levels exhibit three effects on firm profits: a demand-enhancing effect, a unit cost effect, and an investment cost effect. These effects apply to a variety of sustainability investments, ranging from "green investments" that benefit the environment by incorporating eco-efficient features into the product to "social investments" that may benefit, for example, the welfare of production workers as a result of improved safety standards. Consider the rivalry between the two firms. If the owner instructs the manager to maximize profits, the decisions would be made as if there were a single decision-making agent and the game would reduce to a one-stage game. This case is briefly discussed in Section 4.1. The case in which an owner may make use of sustainability incentives is discussed in Section 4.2.

4. Results

4.1. Case: profit maximization incentives

The case in which a manager maximizes profits on behalf of the owner reduces to a single-stage noncooperative game in which the agent of firm i chooses y_i and e_i in anticipation of the rival agent's decisions. Using the subscript p, the outcomes in equilibrium are

$$e_p^* = \frac{\theta(k+1)(a-c)}{N_p}, \quad (3)$$

$$p_p^* = \frac{a(\gamma-(k+1)\theta(\theta-\tau))+c(k+1)(\gamma-\theta\tau)}{N_p}, \quad (4)$$

$$q_p^* = \frac{\gamma(k+1)(a-c)}{N_p}, \quad (5)$$

where $N_p = \gamma(k+2)-(k+1)\theta^2$. From the sufficient second-order conditions (see Appendix A) the lower boundary $\gamma > 0.5(k+1)\theta^2$ follows, which ensures that $N_p > 0$. It follows that in equilibrium, $q_p^* > 0$ always. In addition, Appendix B shows that $p_p^* > 0$ always.

More important, observe that a firm invests in sustainability only if $\theta > 0$. This is the case if sustainability reduces the unit cost of production (i.e., $\beta > 0$). If, in contrast, sustainability raises the unit cost ($\beta < 0$), then $\theta > 0$ only if $-\tau < \beta < 0$. This means not only that a demand-enhancing effect has to be present but also that the demand-enhancing effect has to be stronger than the (negative) cost effect.

Proposition 1. *Suppose that the firm owners instruct their managers to maximize profits. In the feasible parameter space, characterized by $\gamma > 0.5(k+1)\theta^2$, a firm invests in sustainability only if $\theta > 0$.*

4.2. Case: sustainability incentives

The setting with sustainability incentives comprises the following two-stage game. In the second stage, the managers compete in the product market and simultaneously choose product prices and the product's sustainability level to be obtained via investment, while maximizing the salary function $S_i = \pi_i + \lambda_i e_i$. Such linear incentive schemes are frequently observed in the literature and are easy to implement in practice. It is straightforward to show that assuming an additional (constant) base salary, which is common in practice, would not alter managers' decisions and is therefore unnecessary to incorporate. Recall that e_i is the sustainability level of the product offered by firm i. The sustainability level raises demand as consumers exert a willingness to pay for these products, while the firm can make investments to enhance the sustainability level. The interpretation of using e_i in the manager's salary function suggests that it is measurable and that a manager can receive a monetary reward for the level of e_i. A fitting example that could be derived from the Sustainability Accounting Standards Board (SASB) standards is the use of recycled materials in manufacturing firms, such as auto parts or carmakers (SASB, 2017). Indeed, car manufacturers such as Toyota have undertaken serious efforts to invest in projects aimed at a recycling-based society (Toyota, nd). Note that throughout this paper λ_i, $i = 1, 2$, takes a monetary value and will frequently be called the (sustainability) incentive weight. If in equilibrium $\lambda_i^* = \lambda^* > 0$, then the manager is given a "positive incentive' or "positive reward" for the sustainability investments made, as any $e_i > 0$ increases the manager's pay. With such $\lambda^* > 0$, the manager is encouraged to make those investments. Clearly, if $\lambda^* < 0$, the manager is discouraged to make sustainability investments, as the manager's pay will decrease when these investments are made.

In the second stage, the interim equilibrium levels $e_i(\lambda_i, \lambda_j)$, $e_j(\lambda_i, \lambda_j)$, $y_i(\lambda_i, \lambda_j)$, and $y_j(\lambda_i, \lambda_j)$ are found. The outcomes now depend on the incentive weights λ_i and λ_j chosen in the first stage, which illustrates that the managers respond to the incentives offered to them. Second-order conditions in this stage appear in Appendix C.

The second-stage outcomes are substituted into the owners' profit functions. In the first stage, the owners independently maximize their profits and select the equilibrium incentive weights λ_1 and λ_2. As Veldman et al. (2014), for example, show, the firm owner would make sure the manager's participation constraint is exactly met, essentially making the manager's total salary a constant. Thus, the manager's total pay does not have to be subtracted from firm profits while seeking the equilibrium incentive weight λ^*.

The subscript l denotes outcomes in the sustainability incentives case. In equilibrium,

$$e_l^* = \frac{2\theta(k+1)(a-c)\left(\gamma\left(k^2+4k+2\right)-(k+1)(2k+1)\theta^2\right)}{N_l},$$

$$q_l^* = \frac{\gamma(k+1)(a-c)\left(\gamma(k+2)(3k+2)-(k+1)\left(k^2+4k+2\right)\theta^2\right)}{N_l},$$

$$\lambda^* = \frac{-\gamma\theta k^2(k+1)(a-c)(\gamma-(k+1)\theta^2)}{N_l},$$

where $N_l = \gamma^2(k+2)^2(3k+2)-\gamma(k+1)(k+4)(k^2+4k+2)\theta^2 + 2(k+1)^2(2k+1)\theta^4$. The expression of p_l^* is suppressed to save space.

From the second-stage sufficient second-order conditions, the condition $\gamma > 0.5(k+1)\theta^2$ is derived, which ensures that $N_l > 0$. This bound also ensures that $q_l^* > 0$ and $e_l^* > 0$ provided that $\theta > 0$. The latter result is similar to the case without sustainability incentives (Section 4.1).

It can also be observed that the first-stage sufficient second-order condition (see Appendix C) implies that we have a stricter lower bound of the feasible parameter space in this case. The expression is cubic in γ, making it difficult to obtain closed-form solutions. However, an accurate approximation of the lower bound can be obtained, and is given by

$$\gamma > \gamma_A \equiv \frac{(k+1)(5k+4)(2k+1)^2\theta^2}{(3k+2)^3}.$$

The parameter γ_A is used to analyze the positivity of p_l^* (see Appendix D). From this analysis, it can be concluded that the feasible parameter space might contain subspaces that impose additional restrictions on the values of a and c to ensure that p_l^* is positive.

The equilibrium incentive weight λ^* can now be studied. Consider its numerator. Defining $\gamma_L \equiv (k+1)\theta^2$, it can be verified that $\gamma_L > \gamma_A$. More importantly, observe that λ^* is positive (negative) if $\gamma < \gamma_L$ ($\gamma > \gamma_L$). Fig. 1 provides a graphical representation of

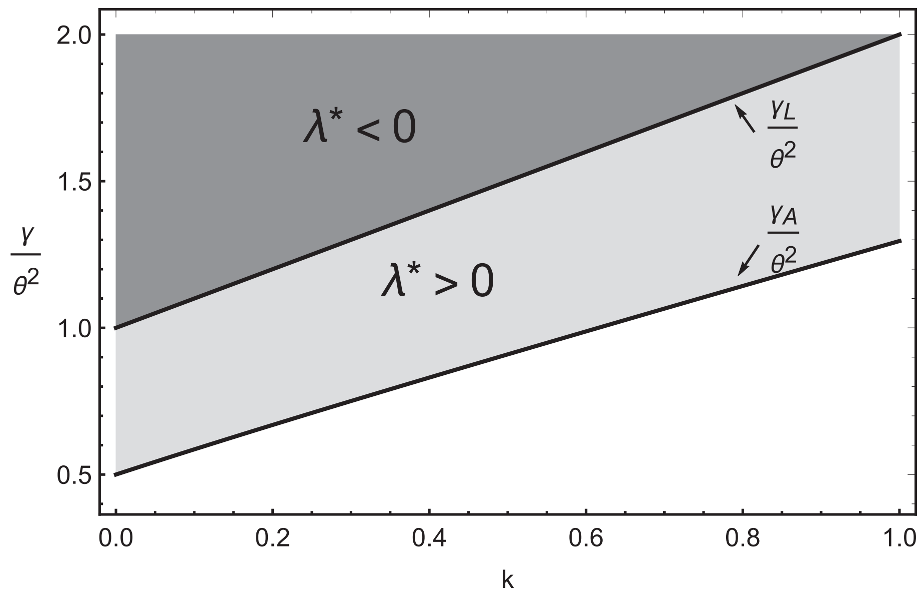

Fig. 1. The sign of λ^* in the feasible parameter area characterized by $\gamma > \gamma_A$ (given any $\theta > 0$).

thresholds γ_A and γ_L, and their implication for the sign of λ^*.

Why would sustainability investments be discouraged if γ is high enough? This question can be answered using the second-stage reaction functions:

$$\frac{\partial p_i}{\partial p_j} = \frac{k(\gamma - (k+1)\beta\theta)}{(k+1)(2\gamma - (k+1)\theta^2)},$$

$$\frac{\partial e_i}{\partial e_j} = \frac{-k\tau\theta}{2\gamma - (k+1)\theta^2},$$

$$\frac{\partial p_i}{\partial e_j} = \frac{-k\tau(\gamma - (k+1)\beta\theta)}{(k+1)(2\gamma - (k+1)\theta^2)},$$

$$\frac{\partial e_i}{\partial p_j} = \frac{k\theta}{2\gamma - (k+1)\theta^2}.$$

It has been observed that $\lambda^* < 0$ if $\gamma > \gamma_L$. If this holds, then product prices are strategic complements, while sustainability levels are strategic substitutes (cf. Bulow et al., 1985). That is, if $\gamma > \gamma_L$, then $\partial p_i/\partial p_j > 0$ and (always) $\partial e_i/\partial e_j < 0$, respectively, for $i = 1, 2; j = 3 - i$. Furthermore, an increase of the sustainability level of firm j will reduce the price of firm i, $\partial p_i/\partial e_j > 0$, in effect reducing the price of firm j due to the strategic complementarity of product prices. This suggests that an increase of a firm's sustainability investments will intensify price competition (and that a reduction of sustainability investments will raise prices). When γ is relatively high, this competition intensification can be considered too costly, suggesting that firm owners prefer to discourage managers from investing in sustainability.

Proposition 2. *In the feasible parameter space, characterized by $\gamma > \gamma_A$, a manager invests in sustainability only if $\theta > 0$. Furthermore, firm owners will encourage managers to make sustainability investments ($\lambda^* > 0$) only if $\gamma_A < \gamma < \gamma_L$. If $\gamma > \gamma_L$, the manager is discouraged from investing in sustainability ($\lambda^* < 0$).*

Finally, observe that the area where positive sustainability rewards are used is given by

$$A = \int_0^\infty (\gamma_L(k,\theta) - \gamma_A(k,\theta))\mathrm{d}k$$
$$= \theta^2 \int_0^\infty \frac{(7k+4)(k+1)^3}{(3k+2)^3}\mathrm{d}k,$$

clearly indicating that the parameter area where positive rewards are used, expands with θ.

4.3. Case comparison

Will sustainability incentives stimulate investment? To answer this question, it is necessary to compare e_p and e_l. It is easy to check that for $\gamma_A < \gamma < \gamma_L$, the firm that uses positive sustainability rewards always invests more. That is, $e_l^* > e_p^*$ if $\lambda^* > 0$, while $e_p^* > e_l^*$ if $\lambda^* < 0$. This is a straightforward result, as managers respond directly to the incentives given to them. The result is also in line with Wang et al. (2018), who conclude from a survey among major U.S. firms that monetary incentives related to climate change performance raise the use of eco-efficiency technologies.

Proposition 3. *Managers who are offered positive sustainability rewards will invest more in sustainability.*

Comparing product prices yields

$$p_p^* - p_l^* = \frac{(a-c)k^2\gamma\theta(\gamma - (k+1)\theta^2)((k+2)\tau - (k+1)\theta)}{M},$$

where $M > 0$ is the product of the denominators of the equilibrium outcomes in both cases. The following proposition summarizes the outcomes of the comparison.

Proposition 4. *Equilibrium prices in the profit incentives and the sustainability incentives cases compare as follows:*

$$p_p^* - p_l^* = \begin{cases} >0, \text{ for } \lambda^* > 0 \text{ and } \beta > \left(\frac{1}{k+1}\right)\tau \\ <0, \text{ for } \lambda^* > 0 \text{ and } \beta < \left(\frac{1}{k+1}\right)\tau \\ >0, \text{ for } \lambda^* < 0 \text{ and } \beta < \left(\frac{1}{k+1}\right)\tau \\ <0, \text{ for } \lambda^* < 0 \text{ and } \beta > \left(\frac{1}{k+1}\right)\tau \end{cases}$$

It is useful to note that $1/(k+1) < 1$ always. The cases will be discussed according to the right-hand-side of the equation in Proposition 4, starting from the top. The use of positive sustainability rewards lowers product prices only if positive β is large enough compared with τ. This suggests that the increased sustainability investments (due to positive sustainability rewards) can allow a price drop only if this price drop is counterbalanced by a large enough cost reduction. If positive rewards are used but β is small (positive) or even negative, the manager will decide to increase prices. When a manager is discouraged from investing in sustainability (which occurs if $\lambda^* < 0$), one could expect that $p_l^* > p_p^*$, in light of a previous finding that a reduction in sustainability investments will raise prices. This occurs only if β is large enough, which suggests that if a large cost reduction is eliminated due to discouraged investments, prices must increase to retain a sufficiently large profit margin.

How will these dynamics affect firm profits? Equating firm profits in the profit incentives and sustainability incentives cases, firm profits increase if a manager is discouraged from investing in sustainability (which occurs if $\gamma > \gamma_L$), while the use of positive rewards reduces firm profits (for $\gamma_A < \gamma < \gamma_L$). The former result shows that in this context, firm owners prefer managers to invest less. A potential explanation is that firm owners often prefer high sales prices over expensive cost reductions. The latter is a typical example of a prisoner's dilemma and a common outcome resulting from positive reward distortions leading to overaggressive strategic behavior (e.g., Berr, 2011), which ultimately results in outcomes below the Pareto optimum.

Proposition 5. *Firms that use positive sustainability rewards will suffer profit losses, while firms that discourage sustainability investments increase their profits.*

Last, the result that rewards are often negative in the feasible parameter space raises the question of how firm profits change in the γ direction. Analytical results are difficult to obtain, so numerical analysis is used instead. Fig. 2 displays how equilibrium profits change with γ for different values of k, given $\theta = 1$. The figures show similar patterns, except that the maximum of firm profits can be identified both in the area where $\lambda^* > 0$ (left panel) and $\lambda^* < 0$ (right panel). The figures suggest that these maximums shift with k. Noting that always $\partial e_l^*/\partial\gamma < 0$, when competition is higher (expressed by a larger k), there is more space to profitably shift from sustainability competition to price competition.

4.5. Firm cooperation

The fact that for the largest part of the feasible parameter area firm owners discourage managers from investing raises the question whether firm owners would prefer to eliminate positive rewards altogether. To analyze this possibility, the game is modified such that in the first stage, firm owners maximize joint profits $\Pi(\lambda_i, \lambda_j) = \pi_i(\lambda_i, \lambda_j) + \pi_j(\lambda_i, \lambda_j)$, and cooperatively determine λ^*. The second stage remains unaltered.

In doing so, the firm owners always set $\lambda^* < 0$, resulting in lower sustainability levels overall (compared with the competitive sustainability incentives case) in the overlapping feasible parameter area.

Proposition 6. *Cooperating firm owners will discourage managers from making sustainability investments.*

This result is reminiscent of the recent fines given by the European Commission to Volvo/ Renault, Daimler, IVECO, and DAF Trucks, for engaging in a cartel (together with MAN) that supposedly revolved not only around prices but also around the introduction of emissions technologies (The Guardian, 2016). Clearly multinational firms sometimes see the benefit of collusion and withholding sustainability investments from the marketplace.

4.6. Robustness – quantity competition

It can now be verified whether the results uncovered so far carry over to a setting that relies on quantities as the main mode of competition. Following Schinkel and Spiegel (2017), the product's price in a differentiated duopoly is

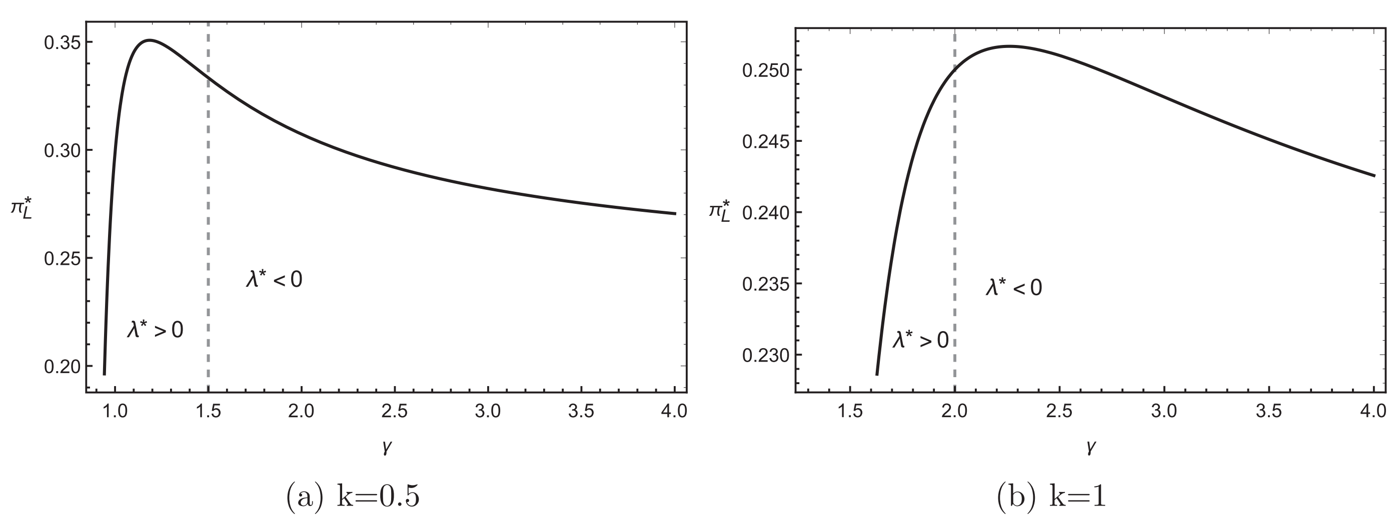

Fig. 2. Change of firm profits with γ for $\theta = 1$.

$$p_i = a - q_i - kq_j + e_i,$$

where $i = 1, 2$, $j = 3 - i$, and $k \in (0, 1)$ measures the degree of product substitutability. If managers are given profit incentives, the game reduces to a one-stage game in which the managers simultaneously choose production quantities and sustainability levels, while all other model elements remain equal. In equilibrium, the managers set a sustainability level

$$e^* = \frac{(a-c)(\beta+1)}{\gamma(k+2) - (\beta+1)^2},$$

which has a strictly positive denominator, as the sufficient second-order conditions require $\gamma > 0.5(\beta+1)^2$. Furthermore, the condition $\beta > -1$ is needed to ensure that $e^* > 0$.

In the sustainability incentives case, the firm owners set

$$e^* = \frac{2(a-c)(\beta+1)\left(2\gamma - (\beta+1)^2\right)}{(k+2)^2(2-k)\gamma^2 + 2(k+4)(\beta+1)^2\gamma - 2(\beta+1)^4},$$

$$\lambda^* = \frac{(a-c)k^2(\beta+1)\gamma^2}{(k+2)^2(2-k)\gamma^2 + 2(k+4)(\beta+1)^2\gamma - 2(\beta+1)^4}.$$

Assuming that $\beta > -1$ and having $\gamma > 0.5(\beta+1)^2$ from the second-stage sufficient second-order condition, a positive denominator is needed to guarantee the positivity of e^*. From this analysis, it follows that the firm owners always set positive rewards for sustainability, resulting in higher sustainability levels compared with the profit incentives case. This result can be explained by the fact that in this framework, sustainability can directly raise a consumers' willingness to pay for the product as well as firm profits without affecting the rival firm's response. Similar results are obtained in, for example, Veldman et al. (2014).

When firm owners cooperate in setting the parameters of their compensation packages, then, in equilibrium,

$$e^* = \frac{2(a-c)(\beta+1)}{(k+2)^2\gamma - 2(\beta+1)^2},$$

$$\lambda^* = -\frac{(a-c)k(\beta+1)\gamma}{(k+2)^2\gamma - 2(\beta+1)^2},$$

from which follows that cooperating firm owners would always use negative rewards for sustainability. This mimics the results obtained in the price competition framework.

5. Conclusions

Sustainability practices and incentives are on the rise. Brand manager pay at L'Oréal, for example, has been linked to several environmental performance indicators since 2016 (GreenBiz, 2016). In 2019, Chevron Corporation announced that it would incorporate greenhouse gas emissions indicators into its incentive schemes offered to executives and tens of thousands of employees (Reuters, 2019). The sustainability incentives within Dutch firms such as Shell, DSM, and AkzoNobel are linked to external benchmarks (based on, e.g., the Dow Jones Sustainability Index) or internal measures, such as CO^2 emission reduction or energy efficiency (Kolk and Perego, 2014). Empirical research shows that companies that have incorporated corporate policies related to the environment and employee well-being into their organization, also tie environmental and social indicators to the incentives schemes offered to their executives (Eccles et al., 2014). Given the myriad developments in practice, it is clear that the calls for using sustainability incentives are becoming more widespread. A series of digital articles in the *Harvard Business Review* argues that companies should incorporate their particular strategic environmental, social, and governance goals into incentive schemes (Burchman, 2018; Burchman and Jones, 2019; Burchman and Sullivan, 2017). The Principles for Responsible Investment (PRI) network, which is supported by the United Nations, states that these practices can help hold managers accountable and stimulate them to search for sustainable value creation, but nevertheless observes that more work is needed (PRI, 2016). Sustainability incentives are being recognized in the academic literature as well (e.g., da Rosa et al., 2019; Wang et al., 2018). However, industrial practice demonstrates that sustainability incentives should be approached with care. For example, it is widely acknowledged that the nature of managerial compensation packages was at the heart of the recent Volkswagen scandal (Li et al., 2018). It is therefore necessary to study sustainability incentives from a variety of perspectives.

Inspired by the analytical and empirical observations in the strategic incentive design literature this paper focuses on how sustainability incentives are designed in the presence of competitors and the effects of these incentives on managers' strategic decisions. Specifically, this paper analyzes the managerial incentives for sustainability investments (or sustainability incentives) and the incentive distortion that arises when profit-maximizing firm owners discourage or encourage managers to invest in sustainability, using positive (negative) rewards that increase (decrease) a manager's pay when the manager makes sustainability investments. This is done with a game-theoretic model consisting of two rival owner–manager pairs. At a general level, this paper identifies a gap in terms of studying sustainability incentives from a strategic point of view. The model presented in this paper is more generic than existing models reported in the literature and differs from the literature in that it features both demand-enhancing and positive or negative cost effects of manufacturing a product with a sustainability level that is determined by sustainability investments.

The use of strategic incentive design is a useful theoretical lens because it provides insight into how rival managers respond to each other's incentive schemes, which could potentially be tied to sustainability investments. From the results summarized in six propositions several conclusions can be drawn. Propositions 1 and 2 show that a manager invests in sustainability only if the product with a higher sustainability level is cheaper to produce than a product with a lower sustainability level or if the demand-enhancing effect of a product with a higher sustainability level outweighs a negative cost effect of such a product. Although these results are straightforward, it is important to carefully examine both demand-enhancing and cost effects of sustainable production. Proposition 2 also states that positive rewards are offered only if the innovation capability of the firm is sufficiently high (given the level of product substitutability, the demand-enhancing effect, and the cost effect of sustainable production). Moreover, whereas positive rewards may lead to increased investment (see Proposition 4), they may also lead to profit losses and a prisoner's dilemma (Proposition 5). In all other cases, firm owners opt for negative rewards, incentivizing the managers to lower their investment levels so that the firms can increase their profits. From these results, which have not been reported in the literature before, it can be concluded that firm owners often actively discourage aggressive sustainability investments by their managers, because it is less expensive to boost profits based on pure price competition rather than investments that increase a product's sustainability level. These results could not have been predicted using the current literature on strategic incentive design (Sengul et al., 2012) and sustainability incentives (e.g. Bian et al., 2016; Dobson and Chakraborty, 2018), because in this body of literature a firm owner's equilibrium strategy is to use positive rewards. According to Proposition 6, cooperating firm owners set sustainability incentives using negative rewards. The main conclusion that can be drawn is that firm owners will always try to prevent their managers from making overaggressive sustainability investments, regardless of the demand-enhancing and cost effects of producing sustainable products. Previous research has already found that coordination of sustainability investments among rivals may lower investments (Schinkel and Spiegel, 2017), and this paper shows that the finding also holds when firm owners coordinate to determine the *incentives* for these investments.

Managerial implications are as follows. Managers and policy makers can also benefit from the results in terms of understanding the best provision of incentives in a competitive (and cooperative) context. In particular, the results indicate that stimulating sustainability investments and improving firm profitability do not go hand-in-hand. Managers can draw from these insights when contemplating the design and effects of sustainability incentives in a strategic context, when considering the effect of manufacturing sustainable products on production cost, consumers' willingness to pay for these products, and the innovation capability of the firm. Moreover, policy makers should be aware of the potential tendency of profit-maximizing firms in an industry to collude and discourage sustainable behavior.

In this paper, the model has intentionally been kept simple, implying that the research has some limitations. Arguably, consumers respond differently to the various dimensions of sustainability, while the decisions underlying these dimensions are not always based on investments (executed in R&D projects) and sustainability incentives. Thus, the model does not capture the full range of sustainability practices observable within firms. Incorporating more sustainability dimensions and practices yields more complex models; nonetheless future studies might consider adding learning-by-doing in existing frameworks and could shed light on the question of how firm owners can most effectively incentivize managers to make smaller (vs. larger) improvements. Other limitations are that the model parameters and outcomes of managerial decisions are deterministic, yet incorporating uncertainty should not drastically alter the paper's results. Finally, in line with other strategic incentive design research (including papers that incorporate some dimension of sustainability into managerial incentives) the current paper assumes that managerial preferences are driven by linear utility functions. However, this may not apply to all managers. It may be worthwhile studying more fine-grained utility functions in future research. Incorporating how some managers invest out of pure conviction and how considering the inclusion of an "appetite for sustainable investment" could affect the model and the resulting outcomes would also be valuable. It would also be interesting to study how government subsidies might help boost sustainability investments while maintaining firm profits, for example, by departing from frameworks such those discussed in Arya and Mittendorf (2015). Future studies could also investigate the structure of sustainability incentives in settings in which more environmentally oriented firms produce green products that increase production cost and only marginally affect consumers' willingness to pay. For example, Wu and Pagell (2011), report that wood product manufacturing firms have difficulty getting price premiums for FSC-certified wood. Finally, in many industries, the outcome of a firm's innovative activity may spill over to a rival. The role of spillovers in the context of sustainability incentives could be a promising topic for future work, especially if policy makers and private firms view the outcome of sustainability investments a public good.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Jasper Veldman: Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing, Project administration. **Gerard Gaalman:** Conceptualization, Methodology, Formal analysis, Writing - review & editing.

Appendix

A Sufficient second-order conditions—profit incentives case

We have $\frac{\partial^2 \pi_i}{\partial y_i^2} = 2(-1-k) < 0$. Also $\frac{\partial^2 \pi_i}{\partial e_i^2} = -\gamma$. The cross-partial derivative is $\frac{\partial^2 \pi_i}{\partial e_i \partial y_i} = -(k+1)\theta$. The determinant of the Hessian matrix yields the condition $\gamma > \frac{1}{2}(k+1)\theta^2$, which has a strictly positive right-hand side.

B When are product prices positive?—profit incentives case

We have $p_p^* > 0$ if $a(\gamma - (k+1)(\theta - \tau)\theta) + c(k+1)(\gamma - \theta\tau) > 0$. Suppose the term $(\gamma - (k+1)(\theta - \tau)\theta)$ is positive, then we can rewrite the inequality to $\frac{a}{c} > \frac{(k+1)(\theta\tau - \gamma)}{\gamma - (k+1)(\theta - \tau)\theta}$. If the right-hand side is smaller than 1, then any value in the feasible parameter area would ensure $p_p^* > 0$, knowing that in our model $a > c$. Verifying the right-hand side we have $\gamma - (k+1)(\theta - \tau)\theta > (k+1)(\theta\tau - \gamma)$, which reduces to $\gamma(k+2) > (k+1)\theta^2$. It follows that $p_p^* > 0$ always, given the conditions that have already been identified.

Let us continue with verifying the assumption that $\gamma - (k+1)(\theta - \tau)\theta > 0$ or $\gamma > (k+1)(\theta - \tau)\theta$. Recall that in this game we need $\gamma > \frac{1}{2}(k+1)\theta^2$. This condition dominates the condition given by $\gamma > (k+1)(\theta - \tau)\theta$ if $\tau > \beta$. If this applies, $p^* > 0$ if $\beta < 0$, and also if $\beta > 0$ and $\tau > \beta$. Furthermore $p^* > 0$ if $\gamma > (k+1)(\theta - \tau)\theta$ and $\beta > \tau$.

Now suppose $\gamma - (k+1)(\theta - \tau)\theta < 0$. It has already been shown that this is possible only if $\beta > 0$ and $\beta > \tau$. Now the inequality should be written as $\frac{a}{c} < \frac{(k+1)(\theta\tau - \gamma)}{\gamma - (k+1)(\theta - \tau)\theta}$. From this follows that this can only be satisfied if the numerator is negative (which is satisfied if $\gamma > \theta\tau$), and $-1[(k+1)(\theta\tau - \gamma)] > -1[(\gamma - (k+1)(\theta - \tau)\theta)]$. Rewriting this yields the condition $\gamma(k+2) > (k+1)\theta^2$, which is always satisfied. Note that considering the direction of the sign of the inequality $\frac{a}{c} < \frac{(k+1)(\theta\tau - \gamma)}{\gamma - (k+1)(\theta - \tau)\theta}$, there are restrictions to the values of a and c.

C Sufficient second-order conditions—sustainability incentives case

In the second stage, we have $\frac{\partial^2 S_i}{\partial y_i^2} = 2(-1-k) < 0$. Also $\frac{\partial^2 S_i}{\partial e_i^2} = -\gamma$. The cross-partial derivative is $\frac{\partial^2 S_i}{\partial e_i \partial y_i} = -(k+1)\theta$. The determinant of the Hessian matrix yields the condition $\gamma > \frac{1}{2}(k+1)\theta^2$, which has a strictly positive right-hand side.

In the first stage,

$$\frac{\partial^2\pi_i}{\partial\lambda_i^2}=\frac{1}{4}\left(-\frac{3k+4}{(k+1)(\gamma(k+2)-(k+1)\theta^2)}-\frac{\gamma k(k+2)}{(\gamma(k+2)-(k+1)\theta^2)^2}-\frac{(2k+1)(5k+4)}{(k+1)(\gamma(3k+2)-(k+1)(2k+1)\theta^2)}+\frac{\gamma k(3k+2)}{(\gamma(3k+2)-(k+1)(2k+1)\theta^2)^2}\right) \tag{C.1}$$

Finding the zeroes of this expression as functions of $\gamma(\theta,k)$ is hard, as rewriting it to a single fraction would yield a cubic numerator in γ. Using Mathematica 11.2® an approximation of the largest zero can be found, expressed as a complex function. However, we can use the zeroes of the different parts of the right-hand side of (C.1) to obtain analytical expressions of a lower boundary, and numerically verify the accuracy of this lower bound compared to the approximation given by the software. The sum of the latter two terms between brackets is negative if

$$\gamma > \gamma_A \equiv \frac{(k+1)(5k+4)(2k+1)^2\theta^2}{(3k+2)^3},$$

while the sum of the first two terms is negative if

$$\gamma > \gamma_B \equiv \frac{(k+1)(3k+4)\theta^2}{(k+2)^3}.$$

It is easy to verify that always $\gamma_A > \gamma_B$, yielding γ_A as a lower boundary. Note that as the first terms of (C.1) are negative if $\gamma > \gamma_B$, the boundary of the parameter space given by γ_A is an overestimation and never an underestimation. Comparing γ_A with the approximation of the lower bound found by Mathematica 11.2® shows that γ_A overestimates the lower bound with less than 1%. For instance, for $k=1000$ and $\theta=1$ the right-hand side of (C.1) becomes negative at $\gamma \approx 738.9$, while $\gamma_A = 741.3$. At $k=1$ and $\theta = 1$, the right-hand side of (C.1) becomes negative at $\gamma \approx 1.287$, while $\gamma_A = 1.296$. Considering the accuracy and simplicity of γ_A and its suitability for setting up proofs, γ_A will be used throughout the paper as a proper lower boundary of the feasible parameter area.

D When are product prices positive?—sustainability incentives case

In the sustainability case, we have $p_l^* = \frac{a\Gamma_1 + c(k+1)\Gamma_2}{N_l}$, where $N_l > 0$, $a > c > 0$,

$$\Gamma_1 = (k+2)(3k+2)\gamma^2 - (k+1)\left(k^2+4k+2\right)(3\theta-2\tau)\theta\gamma - 2(k+1)^2(2k+1)(\tau-\theta)\theta^3,$$

$$\Gamma_2 = (k+1)\left((k+2)(3k+2)\gamma^2 - \left(k^2+4k+2\right) \times (2\tau+\theta+k\theta)\theta\gamma + 2(k+1)(2k+1)\tau\theta^3\right).$$

Note that both Γ_1 and Γ_2 are quadratic in γ and that the zeroes can be easily obtained. Positivity of p_l^* is clearly established if $\Gamma_1 > 0$ and $\Gamma_2 > 0$. We can show numerically that this does not always hold true. Suppose $\tau = 1$. It can easily be demonstrated numerically that there exist parameters θ, k for which the largest root of Γ_1 strictly dominates the boundary condition given by γ_A, suggesting that Γ_1 might be negative in parts of the feasible parameter space given by $\gamma > \gamma_A$. This also holds for Γ_2. That is, Γ_2 might be negative in some parts of the feasible parameter space.

We now need to analyze three sub-areas. Clearly $p_l^* > 0$ in the open area where $\gamma > \gamma_A$, $\gamma > \Gamma_1$ and $\gamma > \Gamma_2$. Furthermore, it can be demonstrated that $p_l^* > 0$ if $\gamma > \gamma_A$, $\gamma > \Gamma_1$ and $\gamma < \Gamma_2$ since a, c can always be scaled such that always $p_l^* > 0$. Finally there might be areas where $\gamma > \gamma_A$, $\gamma > \Gamma_2$ but $\gamma < \Gamma_1$. A necessary condition to ensure positivity of p_l^* (given values of a and c) is that $\Gamma_2 > -\Gamma_1$. We can obtain closed-form solutions for the equation $\Gamma_2 = -\Gamma_1$ and can show that always $\Gamma_2 > -\Gamma_1$ in the area under consideration.

Similar analyses can be made for other values of τ.

E Proof of propositions

Proof of Proposition 2. To develop the proof, it is convenient to start with analyzing the positivity of q_l^*, taking the second-stage second-order condition $\gamma > \frac{1}{2}(k+1)\theta^2$ into account. Suppose $N_l < 0$, then the numerator of q_l^* has to be strictly negative, which is the case if $\gamma < \frac{(k+1)(k^2+4k+2)\theta^2}{(k+2)(3k+2)}$, which contradicts the condition $\gamma > \frac{1}{2}(k+1)\theta^2$. Thus always $N_l > 0$. Consider next e_l^*. We cannot have $\theta < 0$ and $\gamma < \frac{(k+1)(2k+1)\theta^2}{k^2+4k+2}$ as $\frac{(k+1)(2k+1)\theta^2}{k^2+4k+2} < \frac{1}{2}(k+1)\theta^2$. Thus $e_l^* > 0$ only if $\theta > 0$ and $\gamma > \frac{(k+1)(2k+1)\theta^2}{k^2+4k+2}$.

Note that the largest root of N_l, given by

$$\gamma = \frac{(k+1)\left(k^3+8k^2+18k+8+\sqrt{k^4+16k^3+52k^2+56k+20}\right)\theta^2}{2(k+2)^2(3k+2)} \tag{E.1}$$

is always larger than the right-hand side of $\gamma = \frac{(k+1)(2k+1)\theta^2}{k^2+4k+2}$ and the right-hand side of $\gamma = \frac{1}{2}(k+1)\theta^2$, which is the function obtained from the second-stage second-order condition. It can now be verified that the right-hand side of the lower bound of the feasible parameter area γ_A obtained from the first-stage second-order conditions (see section C) is always larger than the right-hand side of (E.1).

Consider λ^*. Knowing that $N_l > 0$ and $\theta > 0$ it is clear that $\lambda^* > 0$ only if $\gamma > \gamma_L \equiv (k+1)\theta^2$. This inequality has a right-hand side that is strictly larger than the lower bound of the feasible parameter space γ_A. That is, $\gamma_L > \gamma_A$. ∎

Proof of Proposition 3. A straightforward comparison of the sustainability level in the case without and with sustainability incentives shows that the levels are equal if $\gamma = (k+1)\theta^2$. A numerical check suffices to show that if $\gamma_A < \gamma < (k+1)\theta^2 \equiv \gamma_L$, sustainability levels are higher for firms using sustainability incentives. ∎

Proof of Proposition 5. Define π_p^* and π_l^* as the firm profits in the case without and with sustainability incentives, respectively. Solving $\pi_p^* = \pi_l^*$ yields the solutions $\gamma = (k+1)\theta^2$ and

$$\gamma = \frac{(k+1)\left(k^3+12k^2+30k+16\pm k\sqrt{k^4+24k^3+84k^2+96k+36}\right)\theta^2}{2(k+2)^2(5k+4)}.$$

It is easy to show that the latter two solutions are not within the feasible area characterized by $\gamma>\gamma_A$. A numerical check suffices to show that if $\gamma_A<\gamma<(k+1)\theta^2\equiv\gamma_L$, $\pi_p^*>\pi_l^*$. Also, if $\gamma>\gamma_L$, $\pi_l^*>\pi_p^*$. ∎

Proof of Proposition 6. We modify the game with sustainability incentives such that in the first stage, the firm owners maximize joint profits $\Pi = \pi_1 + \pi_2$. Note that the outcomes in the second stage remain unchanged. In the first stage, the owners would optimally set

$$\lambda^* = -\frac{(a-c)(k(k+1)\gamma\theta}{\gamma(k+2)^2 - 2(k+1)\theta^2}.$$

This expression has a positive denominator, knowing that $q^* = \frac{(a-c)(k+1)(k+2)\gamma}{\gamma(k+2)^2-2(k+1)\theta^2}$, while in the numerator $\theta>0$ because $e^* = \frac{2(a-c)(k+1)\theta}{\gamma(k+2)^2-2(k+1)\theta^2}>0$ only if $\theta>0$. It can also be calculated that positivity of the denominator ensures that the sufficient second-order condition holds.

From this follows that $\lambda^*<0$ in equilibrium.

Finally, equating the sustainability levels in the competitive and cooperative incentives case yields the solution $\gamma = \frac{(k+1)\theta^2}{k+2}$. This line is clearly dominated by γ_A. It now suffices to use a single numerical check that cooperative incentives always yield lower sustainability levels. ∎

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