A new rationale for not picking low hanging fruits: The separation of ownership and control

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Abstract Recent attempts at explaining the energy-efficiency gap rely on considerations related to organizational and behavioral/cognitive failures. In this paper, we build on the strategic delegation literature to advance a complementary explanation. It is shown that strategic market interaction may encourage business owners to instill a bias against energy efficiency in managerial compensation contracts. Since managers respond to financial incentives, their decisions will reflect this bias, resulting in lack of investment.

Keywords Energy efficiency, strategic delegation, behavioral bias, energy paradox

1 Introduction

The optimization of production processes in combination with the acquisition of innovative energy efficiency solutions enable better energy management and performance. These energy efficiency improvements are beneficial in terms of reducing production costs, strengthening the competitive position of the firm and permiting the achievement of its social and environmental responsibility objectives. In light of this, firms should seize every opportunity to improve their energy efficiency. Yet, ample evidence show that even investments with low initial expenditures and quick returns do not materialize. This paradox – commonly referred to as "the energy efficiency gap" – prompted a large literature on the barriers that prevent firms from improving their energy efficiency.[1]

The energy-efficiency gap refers to the difference between the energy efficiency levels observed and those deemed privately optimal according to engineering studies (Jaffe & Stavins, 1994). The actual extent of this gap is disputed (Sutherland, 1991). Some authors argue that engineering studies may overestimate it by ignoring *hidden costs* (Anderson & Newell, 2004), including those arising from the imperfectly substitutability of technologies, transactions associated with the acquisition of new equipment and services, and firm heterogeneity. Indeed, energy efficiency solutions may have less satisfactory characteristics than standard equipment (e.g., color rendition under cool white Led illumination). Besides, their implementation may involve search, assessment and procurement costs. Lastly, adoption costs vary widely across firms depending on firm specific characteristics (Verhoef & Nijkamp, 2003). Once hidden costs are accounted for, these skeptic authors argue, the remaining energy-efficiency gap, if any, is explained by *market failures* (Koomey & Sanstad, 1994).

Sources of market failures are well documented (Fisher & Rothkopf, 1989). Among these, *information deficiencies* play an important role in impeding investments (Howarth & Anderson, 1993). Firms may simply lack accurate and dependable information about equipment attributes (e.g., energy-efficiency, running costs and reliability). Alternatively, information may be distributed asymmetrically across market participants allowing opportunistic behavior such as *adverse selection*, *moral hazard* and *split incentives* (Gillingham *et al.*, 2009; Gerarden *et al.*, 2017). For example, a company that is unable to confirm the energy-efficiency characteristics of a cost-effective equipment will balk at its price. Anticipating such reluctance from prospective customers, suppliers of energy saving technologies will market only cheap low-performance equipment.

Additionally, market failure may arise from *externalities* (Gerarden *et al.*, 2017). The *limited appropriability* of returns on innovation activities discourages investment in energy-efficiency R&D. Likewise, *learning-by-doing spillovers* incite firms to delay investment to benefit from the continuous flow of knowledge generated by early-adopters. Finally, the market for energy saving equipment may fail because of *capital market failures*, *incomplete markets* and *irreversibilities*.[2]

Market failure arguments may not be sufficient to close the energy-efficiency gap, however. Recent contributions suggest that *organizational issues* (DeCanio, 1993) combine with *behavioral biases* (Tientenberg, 2009; Allcott *et al.*, 2014; Gillingham & Palmer, 2014; Frederiks *et al.*, 2015) to impede investments. Top management is made up of executives who differ in their training, skills, experience and goals. Firm behavior will reflect this complex set of idiosyncrasies (DeCanio, 1993; Cagno *et al.*, 2013). Admittedly, short-term compensation contracts, rapid job rotation, and individual reputation building behaviors aiming at self-promotion convey

[1] For literature surveys, see Sorrell *et al.* 2004; Tientenberg 2009; Gillingham & Palmer 2014; Gerarden *et al.* 2017.

[2] Or, to be more specific, liquidity constraints, risk and losses of future options.

incentives that favor projects that offer a quick return on investment, thereby excluding investment in energy saving equipment (DeCanio, 1993; Sorrell *et al.*, 2004).

Likewise, the *scarce* and *selective managerial attention* precludes the balancing of costs against benefits of investment. DeCanio (1993) notes that "[M]anagement attention and resources are scarce and must be concentrated on those areas deemed crucial to the survival of the firm (p. 910)". To economize on managerial attention, top management relies on simplified decision procedures aiming at satisfactory rather than optimal outcomes. For instance, as a way to reduce managerial discretion while saving on control costs, it may demand an unusually fast return on investment on smaller cost reduction projects, particularly those related to energy savings (Antle & Eppen, 1985; DeCanio, 1993). The adoption of such simple heuristics might be perfectly rational in the face of uncertainty.

Selectivity suggests that managers focus their attention only on the most *salient* issues facing the firm (Frederiks *et al.*, 2015; Gerarden *et al.*, 2017; Cattaneo, 2019). It is reflected in the fact that decisions related to product management or strategic planning clearly enjoy greater standing than is accorded to energy cost savings. It further transpires from the better pay and greater prestige associated with corresponding executive positions. This difference in treatment may, in turn, discourage energy efficiency managers to further invest in human capital (DeCanio, 1993).

Inattention may be perfectly rational. Indeed, faced with prohibitive search and transaction costs and given limited managerial resources, firms may engage in '*rational inattention*', a type of information processing characterized by self-imposed rationality constraints (Sallee, 2014). This could explain why, in actual practice, top managers seem to ignore (or heavily discount) energy cost savings and to focus exclusively on initial investment outlays. However, the differential treatment of benefits and costs may also result from the behavioral biases that top executives hold. *Loss aversion* -- the tendency to avoid losses over acquiring equivalent gains -- may provide part of the explanation. As noted by Cattaneo (2019), "it could be that investment costs are evaluated as a loss and are weighted more than gains". Other behavioral biases may explain why firms exhibit an inertia in adopting new technologies (Frederiks *et al.*, 2015). *Sunk costs effects* may induce firms to retain obsolete equipment in an effort to recoup initial investment outlays. Besides, *endowment effects* may encourage firms to replace faulty (or tired) equipment by similar (or same) apparatus even though innovative cost-effective energy-efficient alternatives are available.

In this paper, we bridge the above three – economic, organizational and behavioral/cognitive – perspectives. Our aim is to show that strategic market interaction may contribute to and even exacerbate behavioral and cognitive biases that are at the source of the energy-efficiency gap. The intuition for this result is based on the separation of ownership and control in modern corporations. We consider a strategic delegation game in which business owners decide whether or not to delegate executive decisions to a professional managers. As shown by Vickers (1985), Fershtman & Judd (1987) and Sklivas (1987), delegation in Cournot markets has strategic value. By hiring a manager, the owner of a firm can *credibly* commit to pursue a goal that differs from maximizing profit. Indeed, the managerial incentives embedded in managerial compensation contracts make the deviation from profit maximization credible since managers respond to financial incentives. Delegation decisions and deviations from profit maximization may thus arise as an equilibrium behavior.[3]

In this game, we assume that production implies energy expenditures. Accordingly, when delegation actually occurs, managers are responsible for both production and energy conservation

[3] For a recent survey of the strategic delegation literature, see Kopel & Pezzino (2018)

decisions. The previous literature focused on deviations from profit maximization involving ingredients of sales revenue, market share or relative profit maximization. By contrast, here, we allow business owners to design compensation contracts that encourage managers to ignore part (or all) of energy costs. Such compensation contracts would result in an unequal weighting of energy costs savings and investment costs. It is shown that they are selected by business owners at the equilibrium of the strategic delegation game. Consequently, what is usually regarded as a cognitive bias – the unequal weighting of energy cost savings and investment costs– is sustained as an equilibrium behavior.

Our model is related to two previous contributions on managerial delegation decisions for polluting firms. In a Cournot duopoly with homogeneous goods and pollution emissions, Barcena-Ruiz & Garzon (2002) find that business owners favor revenue maximization at the expense of profits. Consequently, strategic delegation results in higher output levels and pollution emissions. The optimal environmental tax is then higher than that required to regulate a owner-managed oligopoly. Pal (2012) generalizes this result to industries supplying differentiated products. In both models, stronger managerial incentives (i.e, a lower profit weight) lead managers to pay less attention to production costs with respect to sales revenues.

Our paper differs from these contributions along several important lines. We consider a different kind of deviation from profit maximization that has nothing to do with sales revenues, market share or relative profit objectives. Furthermore, we resort to strategic delegation arguments to explain why modern corporations may weight differently different type of costs – upfront investment outlays aimed at increasing energy conservation and recurring energy expenditures. In so doing, we show that strategic market interaction may contribute to and even exacerbate observed behavioral biases.

The paper is organized as follows. Section 2 describes the model. Section 3 solves the managerial subgame. Section 4 characterizes Subgame-Perfect Nash Equilibrium (SPNE) delegation decisions. The last section concludes.

2 The Model

We consider a duopoly market with two identical firms indexed by $i = 1, 2$. The two firms produce a homogeneous good q and compete in quantities. Let q_i denote firm i's output and $Q = (q_1 + q_2)$ denote industry output. The inverse demand function is linear and given by $p(Q) = a - bQ$ with $a, b > 0$. The production of the final good requires energy inputs. We assume that both firms buy energy inputs from the same energy retailer at a rate (i.e., fixed price), $r > 0$. For sake of simplicity, we assume that firm i's demand for energy inputs is $e_i(q_i, \gamma_i) = q_i - \gamma_i$ where $\gamma_i \geq 0$ denotes firm i's effort at energy conservation. Under this specification, absent of investment in energy efficiency, firms' production technologies are characterized by an unitary energy-output ratio; i.e., $e_i(q_i, 0) = q_i$. Also, energy conservation may be regarded as a substitute for energy consumption.

Obviously, a reduction in energy input use – or an increase in energy conservation– is highly desirable from the firm's perspective. However, further increases in energy conservation require increasingly experienced staff and increasingly specialized capital. Hence, increases in energy conservation come at an increasing cost. To reduce its overall energy consumption by γ_i units, we suppose that firm i incurs a cost equal to $K_i(\gamma_i) = \frac{k}{2}\gamma_i^2$.

Firm i's energy bill writes as $B(q_i, \gamma_i, r) = r(q_i - \gamma_i)$. We restrict our attention to investments in energy efficiency. In particular, we assume away the possibility for firms to sell excess energy back to the energy retailer. This implies that $\gamma_i \leq q_i$ so that Firm i's energy bill is always nonnegative. Also, we assume that consumers (maximal) willingness to pay for the good exceeds the price of energy; i.e., $a > r$. Firm owner-managers seek to maximize profits, which are given by:[4]

$$\pi_i = (a - bQ)\, q_i - r\,(q_i - \gamma_i) - \frac{k}{2}\gamma_i^2, \quad i = 1,2. \tag{1}$$

However, if profitable, owner-managers may choose to divorce ownership from control . In other words, each owner i may delegate day-to-day production decisions to a manager. We assume that managers respond to financial incentives and, accordingly, seek to maximize their compensation. By appropriately designing the managerial compensation contract, each owner is able to direct managers to pursue an objective that differ from profit maximization. Since managerial compensation in publicly traded companies is common knowledge, this strategic move will convey to rival firms the credible commitment to a deviation from (pure) profit-maximization.

Managerial compensation is assumed to depend on managerial performance. Specifically, we assume a two-part compensation scheme $w_i = w_i^F + w_i^V M_i$ consisting of a base salary $w_i^F \geq 0$ and a commission on performance $w_i^V M_i$, where $w_i^V > 0$ is the rate at which the performance measured by M_i is rewarded. Given this scheme, each manager i will maximize M_i in order to maximize its compensation w_i.

To answer the question whether discounting energy costs could be rational, we consider a class of performance measures defined with respect to δ_i by:

$$M_i(\delta_i) = (a - bQ)\, q_i - \delta_i r\,(q_i - \gamma_i) - \frac{k}{2}\gamma_i^2, \quad \text{for all } \delta_i \in [0,1] \text{ and } i = 1,2. \tag{2}$$

By adjusting the value of δ_i, the owner of Firm i generates a continuum of managerial incentives that range from pure-profit maximization ($\delta_i = 1$) to a complete disregard for energy costs ($\delta_i = 0$). One important remark must be made here. Unless δ_i is set to one, the above-defined class of performance measure does not weight equally the different types of costs involved in production. While expenditures aimed at improving energy efficiency are fully accounted for, energy input costs are at least partially ignored. This is consistent with empirical evidence which highlight that economic agents (consumers or firms) display a tendency to weight differently savings and costs. Our purpose here is to show that such a bias may sometimes be rational rather than linked to defeating cognitive illusions. To the best of our knowledge, no other paper in the strategic delegation literature includes such a differential treatment of the different types of costs that the firm faces.

The timing of the game is as follows (See, Figure 1). At the first stage, both firm owners independently and simultaneously decide whether to hire a manager – and if so, design the managerial compensation contract. To state it differently, both owners set the rate at which input energy costs will be discounted so as to maximize profits. At the second stage, firm managers respond to incentives by independently and simultaneously setting their production and energy conservation levels so as to maximize managerial compensation. The game is solved by backward induction for a Subgame-Perfect Nash-Equilibrium (SPNE). Hence the next section is devoted to the analysis of the managerial subgame.

3 Managerial production and investment decisions

At stage two, the managerial incentives embedded in compensation contracts (δ_1, δ_2) have become public knowledge. Given those incentives, each manager i simultaneously and indepen-

[4] Since managerial compensation is intended to secure the participation of managers, it will be equal to their respective (exogeneouly defined) reservation incomes. Consequently, from an owner's perspective, maximizing profit net of compensation is the same as maximizing profit. For more on this point, see Kopel & Pezzino (2018).

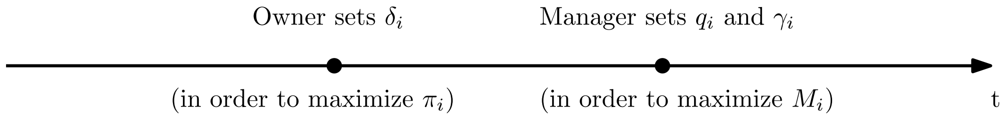


Fig. 1: Timing of the game

dently sets its output q_i and energy conservation effort γ_i to maximize own compensation, taking as given the choices of the manager of the rival firm. A Nash equilibrium of the managerial subgame is a profile of strategies $(q_1^\star, \gamma_1^\star, q_2^\star, \gamma_2^\star)$ such that $(q_i^\star, \gamma_i^\star)$ solves the problem of managerial compensation maximization faced by Manager i for all $i = 1, 2$:[5]

$$\max_{q_i, \gamma_i} M_i = (a - bQ)\, q_i - \delta_i r\,(q_i - \gamma_i) - \frac{k}{2}\gamma_i^2, \qquad \text{(Problem 1)}$$
$$\text{s.t.:} \quad \frac{a}{b} - q_i \geq 0, \quad \gamma_i \geq 0, \quad q_i - \gamma_i \geq 0.$$

The Lagrangean associated with Problem 1 is:

$$\mathscr{L}_i = (a - bQ)\, q_i - \delta_i r\,(q_i - \gamma_i) - \frac{k}{2}\gamma_i^2 + \lambda_i \left(\frac{a}{b} - q_i\right) + \mu_i\,(q_i - \gamma_i) + \nu_i\,(\gamma_i). \tag{3}$$

The Karush-Kuhn-Tucker (KKT) conditions yield:

$$\frac{\partial \mathscr{L}_i}{\partial q_i} = a - 2bq_i - bq_j - \delta_i r - \lambda_i + \mu_i = 0, \tag{4}$$

$$\gamma_i \geq 0, \qquad \frac{\partial \mathscr{L}_i}{\partial \gamma_i} = \delta_i r - k\gamma_i - \mu_i \leq 0, \qquad -\gamma_i\,(\delta_i r - k\gamma_i - \mu_i) = 0, \tag{5}$$

$$\lambda_i \geq 0, \qquad \frac{\partial \mathscr{L}_i}{\partial \lambda_i} = \frac{a}{b} - q_i \geq 0, \qquad \lambda_i \frac{\partial \mathscr{L}_i}{\partial \lambda_i} = \lambda_i \left(\frac{a}{b} - q_i\right) = 0, \tag{6}$$

$$\mu_i \geq 0, \qquad \frac{\partial \mathscr{L}_i}{\partial \mu_i} = q_i - \gamma_i \geq 0, \qquad \mu_i \frac{\partial \mathscr{L}_i}{\partial \mu_i} = \mu_i\,(q_i - \gamma_i) = 0. \tag{7}$$

Due to the concavity of M_i and the linearity of the constraints the above necessary conditions are also sufficient for optimality.

The KKT conditions delineate *up to* four regions of the (δ_1, δ_2) plane, as illustrated in Figure 2a. For the time being, let us assume that these four regions actually exist. Let the lines

$$\ell_j(\delta_i) = \frac{k\,(a + r\delta_i)}{r\,(3b + 2k)}, \quad \ell_i(\delta_i) = \left(2 + \frac{3b}{k}\right)\delta_i - \frac{a}{r}, \tag{8}$$

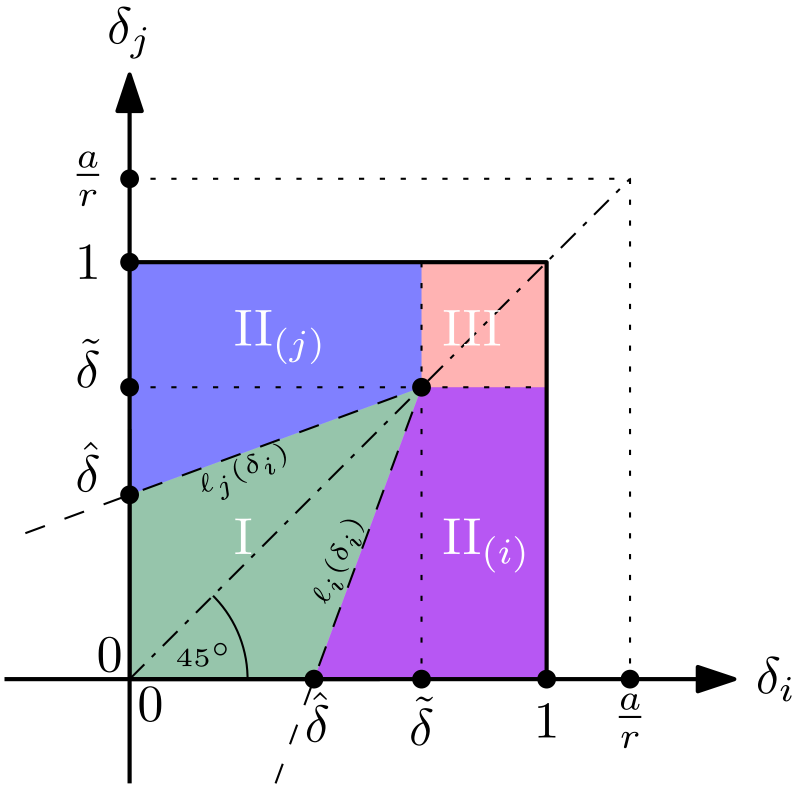
denote the boundaries that delimit the region in which an interior Nash equilibrium obtains. This region, which is labeled I in Figure 2a, may be formally defined as:

$$\text{Region I} = \left\{ (\delta_i, \delta_j) \,\middle|\, 0 \leq \delta_i < \ell_i^{-1}(\delta_j),\, 0 \leq \delta_j < \ell_j(\delta_i) \right\}. \tag{9}$$

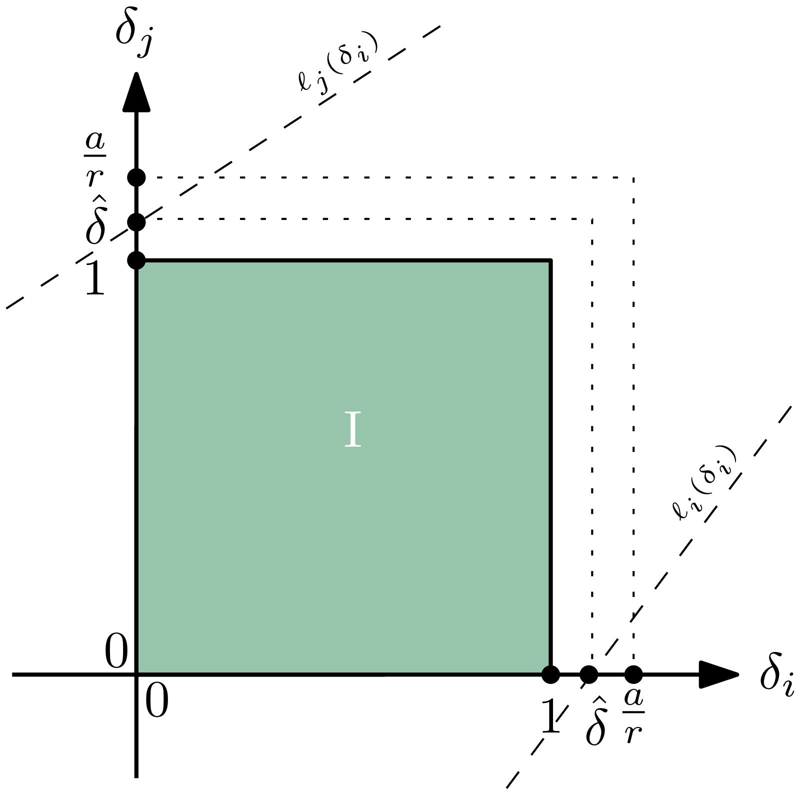
The lines $l_j(\delta_i)$ and $l_i(\delta_i)$ intersect at the point $\left(\tilde{\delta}, \tilde{\delta}\right)$ in the coordinate plane, where

$$\tilde{\delta} = \frac{ak}{r\,(3b + k)}. \tag{10}$$

[5] The assumption that $\frac{a}{b} - q_i \geq 0$ ensures that firm i's strategy set $(i = 1, 2)$ is compact. This condition has obvious economic meaning. It says that manager i would not select a quantity leading to a negative price when firm i is the only active firm in the market.



(a) Four regions associated with four equilibrium configurations



(b) Region I is the unique equilibrium configuration

Fig. 2: Partitioning of the square $[0,1]^2$

This point generates two other boundaries of interest: $\delta_i = \tilde{\delta}$, $i = 1, 2$. Consider the two trapezoid areas labeled $\mathrm{II}_{(k)}$, $k = 1, 2$, in Figure 2a. Region $\mathrm{II}_{(i)}$ is delimited by $\ell_i(\delta_i)$ and $\delta_j = \tilde{\delta}$. It describes the set of all pairs of managerial incentives (δ_1, δ_2) that would induce Manager i to stop buying energy; i.e., to set $\gamma_i = q_i$. Conversely, region $\mathrm{II}_{(j)}$, which is delimited by $\ell_j(\delta_i)$ and $\delta_i = \tilde{\delta}$, describes all (δ_1, δ_2)-pairs that would induce Manager j to set $\gamma_j = q_j$. These two regions may be respectively defined as:

$$\text{Region II(i)} = \left\{ (\delta_i, \delta_j) \middle| \ell_i^{-1}(\delta_j) \leq \delta_i \leq 1, 0 \leq \delta_j < \tilde{\delta} \right\}, \tag{11}$$

$$\text{Region II(j)} = \left\{ (\delta_i, \delta_j) \middle| \ell_j(\delta_i) \leq \delta_j \leq 1, 0 \leq \delta_i < \tilde{\delta} \right\}. \tag{12}$$

A last region, which may be defined as

$$\text{Region III} = \left\{ (\delta_i, \delta_j) \,|\, \delta_i \geq \hat{\delta}, \delta_j \geq \hat{\delta} \right\}, \tag{13}$$

describes the set of all (δ_1, δ_2)-pairs that would induce both managers to stop buying energy ($\gamma_i = q_i$, $i = 1, 2$).

Depending on parameter values, all four regions may not exist. We proceed by characterizing conditions under which only interior Nash equilibria obtains.

Let

$$\hat{\delta} = \frac{ak}{r(3b + 2k)}. \tag{14}$$

From Figure 2a, observe that Region I fully encompasses the subset $[0, 1]^2$ of the coordinate plane whenever $\hat{\delta} > 1$. This will be the case if the price of energy is sufficiently low; Namely, if

$$r < r_1 := \frac{ak}{(3b + 2k)}. \tag{15}$$

Now, if $\hat{\delta} \leq 1$ but $\tilde{\delta} > 1$, or equivalently, if

$$r_1 := \frac{ak}{(3b + 2k)} \leq r < \frac{ak}{(3b + k)} := r_2, \tag{16}$$

then Region III does not exist. Finally, if the price of energy is sufficiently high $(r \geq r_2)$, the KKT conditions partition the $[0, 1]^2$ into four regions.[6]

Equilibrium configurations associated with these four regions are given in Table 1.

	Regions			
	I	$\mathrm{II}_{(i)}$	$\mathrm{II}_{(j)}$	III
Equilibrium	$q_i^I = \frac{a - r(2\delta_i - \delta_j)}{3b}$	$q_i^{\mathrm{II}_{(i)}} = \frac{a + r\delta_j}{3b + 2k}$	$q_i^{\mathrm{II}_{(j)}} = \frac{a(b+k) - r(2b+k)\delta_i}{b(3b+2k)}$	$q_i^{\mathrm{III}} = \gamma_i^{\mathrm{III}} = \frac{a}{(3b+k)}$
	$q_j^I = \frac{a - r(2\delta_j - \delta_i)}{3b}$	$q_j^{\mathrm{II}_{(i)}} = \frac{a(b+k) - r(2b+k)\delta_j}{b(3b+2k)}$	$q_j^{\mathrm{II}_{(j)}} = \frac{a + r\delta_i}{3b + 2k}$	$i = 1, 2.$
	$\gamma_i^I = \frac{r\delta_i}{k}$	$\gamma_i^{\mathrm{II}_{(i)}} = q_i^{\mathrm{II}_{(i)}}$	$\gamma_i^{\mathrm{II}_{(j)}} = \frac{r\delta_i}{k}$	
	$\gamma_j^I = \frac{r\delta_j}{k}$	$\gamma_j^{\mathrm{II}_{(i)}} = \frac{r\delta_j}{k}$	$\gamma_j^{\mathrm{II}_{(j)}} = q_j^{\mathrm{II}_{(j)}}$	
	$p^I = \frac{(a + r(\delta_i + \delta_j))}{3}$	$p^{\mathrm{II}_{(i)}} = \frac{(b+k)(a + r\delta_j)}{(3b+2k)}$	$p^{\mathrm{II}_{(j)}} = \frac{(b+k)(a + r\delta_i)}{(3b+2k)}$	$p^{\mathrm{III}} = \frac{a(b+k)}{3b+k}$

Tab. 1: The four equilibrium configurations

Having completed the analysis of the managerial subgame, we can now turn to the analysis of strategic delegation decisions.

[6] If $r = r_2$ then Region III reduces to the point $(1, 1)$.

4 Delegation and design of managerial compensation contracts

At stage 1, each firm owner decides simultaneously and independently whether to hire a manager, and – if so, sets managerial incentives so as to maximize its profit. As noted above, the KKT conditions delineate *up to* four different regions, each associated with a different equilibrium configuration. Given this partitioning, the profit function of each owner is defined by a piecewise function. Profit maximization then yields piecewise reaction correspondences. Before solving the whole game, we shall consider a reduced model obtained by assuming that the price of energy is low enough to ensure that Region I encompasses the square $[0,1]^2$.

4.1 Low energy price:

Let us recall from section 3 that $r < r_1$ implies $[0,1]^2 \subseteq$ Region I. In other words, for any pair of managerial incentives (δ_i, δ_j) set by firm owners, the equilibrium of the managerial subgame is unique and given by $(q_i^I, \gamma_i^I, q_j^I, \gamma_i^I)$. The profit of Owner i evaluated at the equilibrium is defined by:

$$\pi_i^I(\delta_i, \delta_j) := \pi_i\left(q_i^I(\delta_i, \delta_j), \gamma_i^I(\delta_i, \delta_j), q_j^I(\delta_i, \delta_j), \gamma_i^I(\delta_i, \delta_j)\right), \quad i(\neq j) = 1,2. \tag{17}$$

A pair of managerial incentives (δ_i^I, δ_j^I) is a Subgame-Perfect Nash-Equilibrium of the game among owners if, and only if, $\delta_i^I \in \arg\max_{\delta_i \in [0,1]} \pi_i^I\left(\delta_i, \delta_j^I\right)$ for $i, j\,(i \neq j) = 1,2$. The corresponding first-order conditions are:

$$\frac{\partial \pi_i^I(\delta_i, \delta_j)}{\partial \delta_i} = 0, \quad akr + r^2\left(9b(\delta_i - 1) + (4\delta_i + \delta_j - 6)k\right) = 0, \tag{18}$$

for $i, j\,(i \neq j) = 1,2$. Then, Manager i's reaction function is given by :

$$\delta_i \equiv \phi_i(\delta_j) = \frac{3r(3b+2k) - ak}{(9b+4k)r} - \frac{k}{(9b+4k)}\delta_j, \quad i(\neq j) = 1,2. \tag{19}$$

Since the Hessian matrix is negative definite, $\pi_i^I(\delta_i, \delta_j)$ is strictly concave, and the above necessary conditions are also sufficient for optimality. Solving the system (18) yields

$$\delta_i^\star = 1 - \frac{k(a-r)}{(9b+5k)r}, \quad i = 1,2. \tag{20}$$

Recall our assumption that $\delta_i \in [0,1]$. Observe that $\delta_i^\star < 1$. However, note that $\delta_i^\star < 0$ for

$$0 < r < r_0 := \frac{ak}{3(3b+2k)}. \tag{21}$$

In this case, given the positivity constraint on δ_i, the best Owner i can do is set $\delta_i^I = 0$. We have the following proposition.

Proposition 1. *If the energy rate r is relatively low, the two-stage game admits a unique Subgame-Perfect Nash Equilibrium. At this equilibrium, business owners provide managers with incentives to discount energy costs. Equilibrium discount factors are given by*

$$\delta_i^I = \begin{cases} 0 & \text{if } 0 < r \le r_0, \\ \delta_i^\star, & \text{if } r_0 < r \le r_1, \end{cases} \tag{22}$$

for $i = 1,2$.

From the above proposition it follows that business owners may require management to wholly ignore energy expenditures if the energy rate r is low enough.

4.2 Moderate-to-high energy price

When energy becomes expensive, the question arises as to whether the pair of managerial incentives described by Equation (20) remains a Subgame-Perfect Nash Equilibrium of the game. This will be the case if the strategic pair $(\delta_i^\star, \delta_j^\star)$ satisfies two conditions: (i) it is an element of Region I for $r > r_1$ and (ii) it is immune from unilateral deviations. To begin with, let us check the former condition. Observe that the point $(\delta_i^\star, \delta_j^\star)$ is located along the 45° line for all $r > r_1$. Hence, it is an element of Region I provided that $\delta_i^\star = \delta_j^\star < \tilde{\delta}$ or, equivalently, that

$$r < r_3 := \frac{2ak(2b+k)}{(3b+k)(3b+2k)}. \tag{23}$$

We proceed by checking that the strategic pair $(\delta_i^\star, \delta_j^\star)$ is immune from unilateral deviations. Assume that Owner j contemplates deviating from $\delta_j^\star$ to any $\delta_j^d \in [\ell_j(\delta_i^\star), 1]$. The resulting change in Owner j profit is given by :

$$\pi_j^{\mathrm{II}(j)}\left(\delta_i^\star, \delta_j^d\right) - \pi_j^{\mathrm{I}}\left(\delta_i^\star, \delta_j^\star\right) = \pi_j^{\mathrm{II}(j)}\left(\delta_i^\star\right) - \pi_j^{\mathrm{I}}\left(\delta_i^\star, \delta_j^\star\right), \tag{24}$$

$$= -\frac{(9b+4k)(r(3b+k)(3b+2k) - 2ak(2b+k))^2}{2bk(3b+2k)^2(9b+5k)^2} < 0. \tag{25}$$

Therefore, Owner j has no profitable deviation, and neither does Owner i by symmetry. We can state the following proposition.

Proposition 2. *Unless the price of energy becomes prohibitive* $(r > r_3)$*, the combination of managerial incentives* $(\delta_i^\star, \delta_j^\star)$ is a Subgame-Perfect Nash-Equilibrium outcome.

The question now is whether the game has equilibria in other parts of the coordinate space. The following lemma narrows down the search.

Lemma 1. *Let* $(\delta_i^{c_k}, \delta_j^{c_k})$ *be any pair of managerial incentives from Region* $II_{(k)}$, $k = 1, 2$. *Then,* $(\delta_i^{c_k}, \delta_j^{c_k})$ *cannot be a Subgame-Perfect Nash-Equilibrium.*

Proof. See Appendix A. □

As a consequence of Lemma 1, we need only consider Region III. To simplify exposition, in the remainder of this paper, any equilibrium solution in Region I (resp., III) is referred to as an *interior* (resp., a *corner*) equilibrium. Note that Region III exists if, and only if, $r > r_2$. Furthermore, note that there is an overlap between the interval of energy prices which ensures the existence of an interior solution ($0 < r < r_3$), and that which guarantees that Region III is not empty ($r_2 \leq r < a$). For energy prices in the interval $[r_2, r_3)$, interior and corner equilibria may coexist leading to potential coordination problems. The existence of a corner equilibrium is assured for an energy price greater or equal to

$$r_4 = \frac{ak(2b+k)^2}{(b+k)(3b+k)^2}, \tag{26}$$

as detailed in the following proposition.

Proposition 3. *If* $r \geq r_4$*, then any pair* $(\delta_i, \delta_j) \in$ *Region III is a Subgame-Perfect Nash Equilibrium.*

Proof. See Appendix B. □

The next section discusses our findings.

4.3 Interpretation of the results

Let us combine the results from the previous two sections to describe how the equilibrium behavior of business owners is affected by the price of energy. Reference to Figure 3 will be of assistance for the reader here. When the price of energy is very low ($r \in (0, r_0]$), competition concerns trump energy saving concerns. Indeed, the increase in sales revenues more than compensates for the increased expenditures in energy inputs. Thus, business owners strategically take advantage of delegation to commit their managers to be more aggressive on the product market. This is done by designing compensation contracts so as to encourage managers to ignore energy costs in their everyday production and investment decisions. Compensation contracts then require that managerial performance be evaluated and rewarded solely in terms of sales revenue net of capital expenditures – thus explicitly excluding energy cost savings. In that event, top managers regard investment as both costly and irrelevant because it does not contribute to their compensation. Investment in energy efficiency is then effectively deterred.

Apart from this specific case, business owners have to strike a balance between competitive and energy saving concerns. Accordingly, for $r > r_0$, they set non-zero discount factors. From Equation 20, we have the following comparative statics result:

$$\frac{\partial \delta_i^\star}{\partial r} = \frac{ak}{(9b+5k)\,r^2} > 0, \quad \text{for } r_0 < r < r_3. \tag{27}$$

Namely, the equilibrium weight $\delta_i^\star$ is monotonically increasing on (r_0, r_3) implying that an increase in the price of energy justifies greater attention to energy costs. However, there are two caveats here. First, note that $\delta_i^\star$ is bounded from above by:

$$\delta_{\max}^\star = \lim_{r \to r_3} \delta_i^\star(r) = 1 - \frac{b}{2\,(2b+k)}. \tag{28}$$

This upper-bound originates from the fact that values of δ_i larger than $\tilde{\delta}$ are associated with a different equilibrium configuration in the managerial subgame (i.e., that which corresponds to Region III). Accordingly, small changes in the energy rate around $r = r_3$ may lead to jumps in equilibrium discount rate for there are multiple Nash equilibria on which business owners may coordinate.

When the price of energy becomes cost-prohibitive ($r > r_3$), energy savings become the dominant concern for business owners. Indeed, the increase in sales revenues no longer compensates for increased expenditures in energy inputs. Consequently, at the equilibrium, the two business owners choose relatively high discount factor $\left(\delta_i > \tilde{\delta}\right)$. Thereby, they encourage managers to close the energy-efficiency gap by setting $q_i = \gamma_i$. In that case, the energy costs borne by the two firms are zero and, thus, changes in the value of δ restricted to the interval $[\tilde{\delta}, 1]$ alter neither managerial production and investment decisions nor business owners profits. Correspondingly, the set of Subgame Perfect Nash Equilibrium discount rates is given by $[\tilde{\delta}, 1]^2$. Besides, profit maximization is a natural focal point because business owners are indifferent between all their equilibrium strategies including $\delta_i = 1$. Under the circumstances, business owners may successfully coordinate their hiring and compensation decisions so that delegation does not occur and the industry remains owner-managed. The differents components of cost will then be weighted the same at the managerial level.

Second, observe however that this set of corner equilibria emerges for relatively high – but not necessarily cost-prohibitive – energy prices ($r \geq r_4$). Hence, the two equilibrium configurations ('interior' and 'corner') coexist provided that $r \in [r_4, r_3)$. Furthermore, there is a threshold

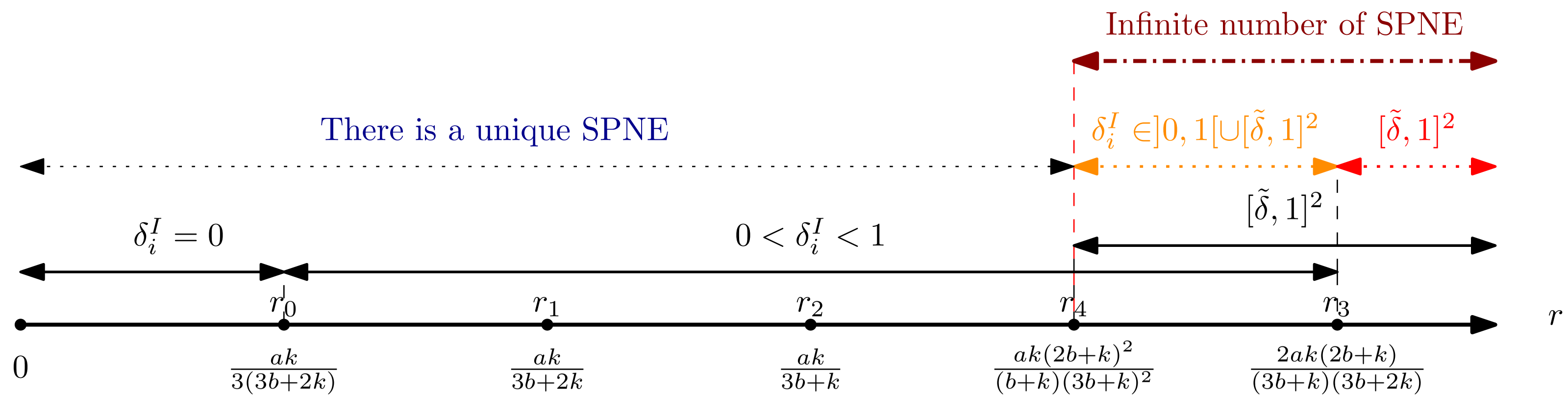


Fig. 3: Existence and unicity of SPNE

value[7] for the energy rate below (resp., above) which the 'interior' equilibrium Pareto dominates (resp., is Pareto dominated by) 'corner' equilibria. In that case, business owners face a coordination game. Here again, profit maximization provides a focal point for business owners. However, efficiency arguments may support delegation decisions.

5 Conclusion

Empirical research highlight that firms exhibit behavioral biases in their energy efficiency investment decisions. It appears that managers attribute less weight in their decision-making to potentially achievable savings than to the initial investment cost. Uncertainty and irreversibility of investment fail to explain this difference in treatment between the various components of the firm's profit function. Recent explanations have suggested the possibility that behavioral biases such as loss aversion or sunk cost effects may explain why profit maximizing investments in energy efficiency are sometimes not undertaken.

In this paper, we proposed a complementary explanation based on strategic delegation theory. It was shown that imperfect competition may encourage business owners to manipulate the terms of managerial compensation contracts to reward investment behaviors exhibiting a bias against energy efficiency. In this case, the performance measure used to assess managerial effectiveness and compensation attributes more weight to investment costs than to energy related cost savings.

The rate at which energy costs are discounted is shown to depend on the price of energy. When the price of energy is low, competitive concerns dwarf energy cost concerns. Consequently, business owners encourage managers to ignore energy expenditures. However, as the price of energy increases, energy costs weight more in decision-making. Accordingly, owners encourage managers to be increasingly attentive not to waste energy. Finally, in scenarios where the price of energy is prohibitive, there are multiple rational behaviors and coordination issues arise.

The explanation we propose is not intended to replace existing organizational and behavioral explanations. Rather, it aims to emphasize that these accounts can be reinforced by strategic considerations. Contrary to a widely held belief, market competition may play a role - albeit limited - in explaining the maintenance of the energy-efficiency gap.

An important managerial insight from our analysis is that managerial compensation contracts should reflect energy market conditions. When energy prices are high, managers should be encouraged to monitor carefully energy costs and invest in energy efficiency. Conversely, when energy prices are low, they should be encouraged to focus on competitive issues. Modeling uncertainty regarding energy prices is a possible avenue for extension of the results of the present contribution.

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[7] We omit the expression of this threshold because it is very lengthy

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Appendices

A Proof of Lemma 1

Let $\mathrm{BR}_i(x)$ denote the set of decisions that are best-responses to a decision x for player i, $i = 1,2$. Let $(\delta_i^{c_k}, \delta_j^{c_k})$ be any pair of managerial incentives from Region $\mathrm{II}_{(k)}$, $k = 1,2$. Assume that $(\delta_i^{c_k}, \delta_j^{c_k})$ is an equilibrium point. Then, $\delta_j^{c_k} \in \mathrm{BR}_j(\delta_i^{c_k})$ where $\mathrm{BR}_j(\delta_i^{c_k}) = [\ell_j(\delta_i), 1]$. Since the game is symmetric, it must be the case that $\delta_i^{c_k} \in \mathrm{BR}_i(\delta_j^{c_k})$ where $\mathrm{BR}_i(\delta_j^{c_k}) = [\ell_i^{-1}(\delta_i), 1]$. Now, observe that $\mathrm{BR}_i(\delta_j^{c_k}) \cap \mathrm{BR}_j(\delta_i^{c_k}) = \emptyset$ since these two sets lie on opposite sides of the 45° line. We conclude that $(\delta_i^{c_k}, \delta_j^{c_k})$ are not mutual best-responses. To complete the proof, observe that the same holds for any point $(\delta_i^{c_k}, \delta_j^{c_k})$ in Region $\mathrm{II}_{(k)}$, $k = 1,2$.

B Proof of Proposition 3

The idea of the proof is illustrated in Figure 4. Consider any $\delta_j \in \left[\tilde{\delta}, 1\right]$. Then, δ_i is a best-

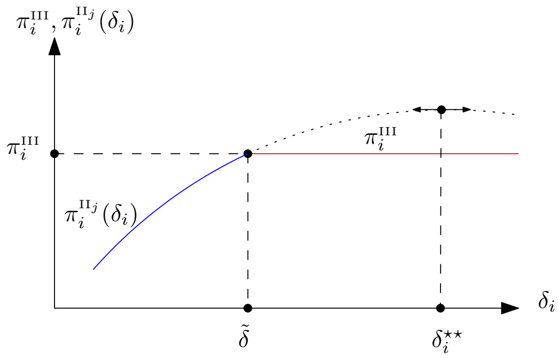

Fig. 4: The idea behind Proposition 3

reply to δ_j if $\pi_i^{\mathrm{III}} \geq \pi_i^{\mathrm{II}_{(j)}}(\delta_i)$. Observe that Firm i's profit function is continuous in $\tilde{\delta}$. Indeed, we have: $\lim_{\delta_i \to \tilde{\delta}} \pi_i^{\mathrm{II}_{(j)}}(\delta_i) = \pi_i^{\mathrm{III}}\left(\tilde{\delta}\right)$. Now, observe that Owner i's profit function is strictly concave since

$$\frac{\partial^2 \pi_i^{\mathrm{II}_{(j)}}(\delta_i)}{\partial \delta_i^2} = -\frac{r^2\left(9b^3+16b^2k+10bk^2+2k^3\right)}{bk(3b+2k)^2} < 0. \tag{29}$$

and reaches a maximum for

$$\delta_i^{\star\star} = \frac{(b+k)(r(3b+k)(3b+2k)-abk)}{t\left(9b^3+16b^2k+10bk^2+2k^3\right)}. \tag{30}$$

Hence, $\pi_i^{\mathrm{III}} \geq \pi_i^{\mathrm{II}_{(j)}}(\delta_i)$ if $\delta_i^{\star\star} \geq \tilde{\delta}$ or, equivalently, if

$$\delta_i^{\star\star} - \tilde{\delta} = -\frac{(3b+2k)\left(ak(2b+k)^2 - r(b+k)(3b+k)^2\right)}{t(3b+k)\left(9b^3+16b^2k+10bk^2+2k^3\right)} \geq 0. \tag{31}$$

The proof is completed by noting that Condition (31) holds provided that $r \geq r_4$.

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