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Partially observable corporate social responsiblity: the limits of differentiation*

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Abstract

We investigate investment incentives in credence corporate social responsibility (CCSR) under different market structures. In duopoly, for high enough market transparency the firms differentiate their product by (only) one of them investing in the SR (clean) technology. If the firms merge, with high enough market transparency (and product traceability) the monopolist also invests in (only) one plant but the necessary market transparency is higher, so competition promotes CCSR. When market transparency lacks product traceability, whenever the monopolist invests it is in both plants, but the consumer information needed regarding the technologies being used by the firm is even higher. Overall we find that the market pushes toward product differentiation, which is both good and bad: there is usually some

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investment by a firm, but also some factory producing with the dirty technology. We conclude that "green" competition policy must be nuanced, taking into account (or regulating) both transparency and traceability.

JEL Classification: L14, L83

Key words: Credence goods, Asymmetric Information, Transparency, Traceability.

1 Introduction

The social and environmental crises that the whole world faces, among which climate change is salient, warrant a variety of public policy responses (the Green Deal in the EU and the US, emission-trading schemes for CO_2, etc.) There is also room, however, for corporate social responsibility (CSR) to address these social and environmental issues, beyond firms' mere compliance with regulatory requirements. In order to understand the role that CSR can play it is crucial to study in which way market structure provides incentives for CSR. In particular, we focus on two dimensions, its transparency and competition. Both aspects are definitely relevant for CSR, as shown by the policy debates surrounding them. On the one hand, the European Commission has written a Proposal for a Corporate Sustainability Reporting which would increase the scope of its Non-Financial Reporting Directive (Directive 2014/95/EU) on the information on firms' social and environmental impacts. On the other hand, antitrust authorities debate on how competition policy can best support the Green Deal, both in the United States and in the European Union. Namely, whether more intense market competition provides firms with extra incentives to invest in green and sustainable technologies, or, rather, whether antitrust authorities should weaken or even exempt horizontal agreements among firms from antitrust liability. Hence, a joint analysis of the impact of competition & transparency on CSR seems warranted, and it is the main contribution of this paper.

We view CSR as a case of 'delegated philanthropy' by the firm, acting on behalf of its stakeholders' – consumers, in our case – values (Benabou and Tirole, 2010). In other words, we take CSR as being strategic, namely, as a response by a for profit firm to a market ethical demand (Baron, 2003). In particular, we model CSR as the supply of a socially responsible credence attribute valued by responsible consumers, an attribute attached to a private good (as in Baron, 2011, and Calveras and Ganuza, 2016). Indeed, many of the attributes that make a good 'green' or SR are credence attributes, not directly observable by consumers (or other stakeholders), who cannot learn about them through neither search nor experience (Nelson, 1970; Baron, 2011; Calveras and Ganuza, 2016). Examples of such attributes are numerous: the conditions under which the product is produced (including any externalities associated with production, for example, pollution and how workers are treated and how well they are paid), hidden hazards associated with consumption of the product, etc.

This asymmetry of information between a firm and its stakeholders regarding the firm's business practices poses a threat to the viability of CCSR. As Calveras and Ganuza (2016) show, to the extent that strategic (for-profit) CCSR is mainly driven by the demand of "ethical" stakeholders (say, consumers who are willing to pay a higher price for a good that incorporates these credence attributes), the level and accuracy of the information available to consumers is key in providing firms with the adequate investment incentives. Absent sufficient transparency (credible information), the market might fail to provide the credence attributes valued by consumers: if consumers are uncertain about the attributes of the good, then they might not be willing to pay a premium and, thus, firms will not supply such attributes in the first place (Akerlof, 1970; Calveras and Ganuza, 2016). As a consequence, the only way CCSR may be part of an equilibrium is when sufficient information is provided by a credible third party (Dulleck and Kerschbamer, 2006).

We start the analysis with a benchmark model where a monopolist (the M) has to decide whether to invest in a "clean" technology, a technology that generates a large positive externality (relative to the currently used, "dirty" one). The M runs two factories (think, for instance, of the monopoly as being the result of a merger), thus, it is feasible for her to invest in one of the factories but not in the other. We acknowledge in our analysis not only the relevance of market transparency for CSR, also the fact that such transparency potentially has many facets. Hence, we explicitly model two dimensions: (i) investment/technology transparency, and (ii) product traceability (PT). The former is the degree to which consumers are informed about the M's investments (in one, both or none of the factories). The latter is their information regarding in which factory a given product has been manufactured.

In particular, we assume that whether the firm invests is its private information, not observable by consumers, though they might have access to credible information (available from third parties, such as NGOs) before their purchase decision. The probability that a revealing (public) signal arrives is our measure of investment transparency. We consider two scenarios regarding the presence of product traceability: either there is perfect product traceability, or there is none whatsoever. In the former, consumers can tell in which factory the good was produced and, thus, the M is potentially able to offer differentiated product varieties according to whether they come from the (supposedly) clean factory. We show that a high enough level of investment transparency is necessary for the M to invest at all, as in Calveras and Ganuza (2016). More interestingly, we find that the M will always prefer to supply both product varieties (one produced with the clean technology and the other with the dirty one) even when the market is fully transparent and scale economies for investing in the clean technology are very strong (the marginal cost of the second investment is zero). It is optimal for the monopolist to keep supplying the dirty product so as to be able to price discriminate between consumers of high and low willingness to pay for consuming a good with the SR credence attribute.

In the second scenario, where consumers cannot tell the origin of the good they are about to buy, the M is unable to product differentiate (between the clean and the dirty product).[1] She can still decide to invest in only one plant, but can only charge one price and consumers have to make a probabilistic judgment of the cleanness of the product. In this case, we obtain that when transparency regarding firm investments is sufficiently high (it needs to be even higher than with traceability), M will invest in both plants, and otherwise in none; the M will never choose to invest in one plant. We conclude from this that the result in the traceable case is indeed the consequence of the ability to price

[1] Think of the proportion of "green" electrons in electric current, for example, or of the percentage of organic cotton in a T-shirt.

discriminate and it is not caused by the ability to fine tune the level of CCSR.

Next, we consider a framework with two firms, with one plant each, that compete in prices after having (privately) decided whether to invest in the clean technology. As in the case of monopoly, product differentiation comes to the fore, showing that it is never an equilibrium that both firms invest. The firms specialize, one producing with the clean and the other with the dirty technology, hence softening price competition. We also find that the necessary level of market transparency for investment in a duopoly is lower than in a monopoly, allowing us thus to conclude that – for medium levels of transparency – competition promotes CSR. The result's rationale is that the incentives that exist for product differentiation in order to soften price competition in the duopoly are stronger than those that exist in a monopoly to price discriminate.

Overall, our analysis shows that the market pushes towards product differentiation in firms' offerings, in both the monopoly and duopoly market structure, meaning that it is likely that both the clean and the dirty varieties will be supplied (given there is sufficient market transparency). The rationale for such a push towards product differentiation lies in firms' incentives to price discriminate (in the case of the monopolist) or to soften price competition (in the duopoly). Such a push towards product differentiation is both good and bad. On the one hand, it is good because the market is indeed likely to supply the clean variety; on the other hand, it is bad as the market (also) supplies the dirty variety, even when market transparency and scale economies of investing are very high.

1.1 Related literature

As we model CSR as the supply of a SR credence attribute attached to a private good, the only way CSR may be part of an equilibrium is when a credible third party provides sufficient information (Dulleck and Kerschbamer, 2006).[2] Several institutions cope with

[2]Markets of credence goods have been analysed, for instance, by Emons (1995) and Wolinsky (1993, 1995) on car repair services, taxi cab rides, and medical treatments. More recently, Dulleck and Kerschbamer (2006) show that (similarly to the Akerlof, 1970, lemons model), when "consumers can neither observe the type of treatment [SR attribute] they get, nor can they punish the expert [the firm in our set-up] if they realize ex post that the type of treatment they received is not sufficient," then no trade

consumers' lack of information on the credence SR attributes supplied by firms: certifications, whether provided by a single firm (Bottega and de Freitas, 2008; Manasakis et al., 2013) or a group (club) of them (Baron, 2011); activists such as NGOs (Feddersen and Gilligan, 2001) in the context of private politics (Baron, 2003, 2005); direct (advertisement) or indirect communication by firms; and the media (Dyck and Zingales, 2002). While previous literature mostly assumes that such an institution fully eliminates the information asymmetry, we instead study the impact of an exogenous increase or decrease in the level of market transparency on the firms' behaviour.[3]

One of our contributions is to distinguish between two dimensions of market transparency: in which technologies did the firm invest in (investment transparency), and which technologies have been used to produce a given good (product traceability). While the former type has been considered before in the analysis of CCSR (as, for instance, in Calveras and Ganuza, 2016), the theoretical analysis of the latter (product traceability) in relation to CCSR is a novelty of the current paper. There are indeed emprical studies of the link between traceability and CCSR, and these focus on issues such as the impact of traceability on consumers' willingness to pay, showing a positive effect (e.g., Bradu et al., 2014; Calderon-Monge et al., 2020); or the role of traceability in food supply chains and firms' sustainability strategies (Bailey et al., 2018; Wiese and Toporowski, 2013). To our knowledge, however, there are no theoretical analyses providing nuance to different types of market transparency. Our analysis shows that such distinction between investment transparency and product traceability is relevant.

The impact of the intensity of competition on CSR has been studied before, both empirically and theoretically. While empirical evidence tends to support the view that competition increases CSR (see Fernandez-Kranz and Santalo, 2010; Bartling et al., 2015; Flammer, 2015; Ding et al., 2020; Aghion et al., 2021) – though a few studies show a negative effect (e.g., Duanmu et al., 2018) – theoretically the results are less clear cut.

will take place and the credence good market ceases to exist (Dulleck and Kerschbamer, 2006, p. 29). Notice this is precisely the situation of CCSR.

[3]Recently, Bottega and Freitas (2019) study imperfect certification in a Bertrand duopoly. Their objective is the analysis of the certification process, that we consider exogenous, and they do not analyse incentives to invest in technology or quality, which they take as being exogenous

We discuss and focus here on the analysis of strategic CSR (rather than moral CSR; see Shleifer, 2004, and more recently, Dewatripont and Tirole, 2020, for an analysis of the way in which competition impacts moral CSR). One of the seminal analyses is that of Besley and Ghatak (2007) who analyse the feasibility of CSR when there is competition among SR and no-SR firms, showing that (i) CSR viewed as attaching a public good to a private good may indeed exist in a competitive equilibrium, and (ii) an increase in market competition reduces the supply of the public good (CSR) attached to the private good, analogous to what would happen in a game of a voluntary private provision of a public good. In contrast, Aghion et al (2021)'s model shows competition increasing firms' incentives to innovate 'clean' rather than dirty: innovation allows the firm to escape competition and charge a higher price; in their model, however, more competition does not increase the number of firms that may innovate (exogenously given), simply reduces profits in the competitive non-innovative segment of the market.

These (and other) papers consider a framework of perfect information, being thus unable to discuss the role that market transparency, as part of market structure, plays in CSR, and how it interacts with market competition. Instead, and closest to our analysis, Calveras and Ganuza (2016) also model CSR as a credence attribute, showing that an increase in market competition decreases CSR. Their rationale is the so-called "margin effect" whereby more intense competition in the SR segment reduces the margin to be gained from CCSR (investing in the clean technology), and hence the incentives to do so. This result is the basis for the substitutability they find between market competition and transparency: the stronger market competition is, the higher its transparency ought to be in order to provide firms with incentives towards CCSR.

Our analysis and modelling of competition differs significantly from that of Calveras and Ganuza (2016): we compare monopoly with duopoly, showing that the latter is likely to show a higher level of investments in the clean technology. While incentives for CCSR are present both in the monopoly (so as to be able to price discriminate) and the duopoly (to soften price competition), the latter are stronger, yielding our result that competition likely fosters CCSR. Our framework in which all firms endogenously pick their technology (we do not have a competitive fringe of firms using the dirty technology and earning zero profits), provides a better model where to study firms' incentives for CCSR. In particular, and contrary to what Calveras and Ganuza (2016) find, we show that market competition may be complementary to market transparency: transparency is 'more productive' in inducing firms' investment in the clean technology when competition is stronger (that is, a lower level of transparency is needed in a duopoly than in monopoly to foster a firm's investment in the clean technology).[4]

The paper now proceeds as follows. We first introduce and discuss our modelling assumptions in Section 2, then solve the cases of monopoly and of duopoly in Sections 3 and 4. Section 5 compares the two market structures, and Section 6 provides some concluding remarks.

2 The model

We model a market for a homogeneous good to which firms may attach a SR attribute. For concreteness, we refer to firms deciding whether to invest in a clean(er) production technology. We first present our model and then discuss our main assumptions.

Technology

There are two firms that operate a production plant each. Originally, they have the "dirty" (D) technology installed. At cost $F > 0$ they can upgrade to a "clean" (C) technology. If the firms merge, the M may benefit from economies of scale in refitting: upgrading both plants costs $(1+k)F$, $k \in [0, 1]$. There is no additional fixed cost and the variable cost of producing x units of the good in a plant is $c(x) = \frac{1}{2}x^2$, independently of the technology used. Notice that the marginal costs of production are increasing,[5] namely, $c'(x) = x$ for a duopolist and $c_2'(x) = x/2$ for the M (when sharing production efficiently between the two plants).

[4] See Brynjolfsson and Milgrom (2012) for an in-depth analysis of complementary and substitutable instruments.

[5] Apart from being realistic, this enables firms to make a positive profit in homogeneous-product price competition, and thus makes it affordable to invest in clean technology.

Externalities

A switch to the clean technology in the production process generates a *large* positive externality on society. We do not model it explicitly. Rather we assume throughout our analysis that the externality dwarfs other considerations: the more plants use the clean technology, the higher social welfare is.

Consumers

There is a unit mass of consumers $i \in [0, 1]$, with heterogeneous, quasi-linear utility from purchasing a single unit of the good (they have no demand for a second unit, and not purchasing gives them zero utility):

$$u_i^C = 1 + wi - p \quad \text{and} \quad u_i^D = 1 - p,$$

(supposedly) produced with the clean and dirty technology, respectively. Here 1 is the consumption value of the good, which does not depend on the technology. wi represents consumer i's marginal valuation of buying a good (supposedly) produced with the clean technology. In other words, wi denotes the degree of warm-glow that consumer i derives from purchasing a SR product (Andreoni, 2006). Here $w \in [0, 1.5]$ is the parameter capturing the size/importance of the "warm glow" element in the consumers' utility (relative to the consumption value). Finally, p is the price paid by the consumers.

Information structure: market transparency

We consider two dimensions of market transparency: one regarding the investment decisions of the firm, namely, the technology/ies used by the firm (investment transparency), and the other regarding the technology used to manufacture a given product (product traceability).

1. **Investment transparency**. Investments and, thus, the technology used by each firm is its private information. However, with exogenous probability γ, a public fully-revealing signal is released to all agents about the technology of all plants (say,

by action of the media, NGOs, certification, etc.). With the remaining probability, no information is released and full asymmetric information remains. In this case, as it will be explained below when specifying the equilibrium concept, consumers have their beliefs, which may be updated according to all relevant information (e.g., prices). In any case, γ represents the degree of *investment transparency*, the amount of information available to consumers regarding the technology used by the firm(s) in each plant. This measure is a *firm-level indicator*, but – even in the case of a fully revealing signal – it does not always allow the consumer to ascertain the technology the product offered to her has been produced with.

2. **Product traceability**. When a product is traceable, the consumer knows the factory it has been produced in. In conjunction with the information on investment she can then evaluate whether the product has been produced with the clean technology.[6]

Product Market

In a monopoly the M sets the price(s)[7] and consumers decide whether to buy. When there are two firms, in principle, we would want to model competition à la Bertrand. As we will see, there are two situations: when firms look identical (show the same signal or there is no signal but in equilibrium they are expected to act the same way), and when not. With symmetry, Bertrand competition with increasing marginal cost is not straightforward, since simultaneous price setting leads to multiple equilibria (Dastidar, 1995). We assume that the players will coordinate on the competitive equilibrium, where price equals marginal cost (but profits are positive).[8] Indifferent consumers randomize fifty-fifty between the firms but buy if indifferent on the extensive margin. When two firms generate different posteriors, they compete à la Bertrand with differentiated products

[6] Notice that the presence (or lack thereof) of product traceability is relevant for the case in which the monopoly invests differently in each of its plants: it is then important for a consumer to be aware of in which factory a good was produced.

[7] If and only if there is product traceability the M can set different prices.

[8] This choice is not arbitrary, it can be rationalized in various ways (cf. Dixon, 1992, Inderst, 2008, Burguet and Sákovics, 2017).

(which, due to the heterogeneous valuations, has a unique equilibrium), setting marginal revenue equal to marginal cost.

The timing

The timing of the strategic interaction is as follows, taking into account the scenario regarding product traceability:

1. Firms simultaneously choose their technology (and pay the fixed cost, if due).
2. With probability γ, there is a public announcement revealing the investment (technology) of each plant.
3. Firms simultaneously set prices.
4. Consumers simultaneously decide whether to accept any offer.
5. Production takes place and payoffs are realized.

Equilibrium

Due to the (potential) unobservability of investment, solving our game requires looking for Perfect Bayesian Equilibria (PBE). A PBE is a set of strategies and beliefs (about unobserved actions) for each player such that, at any stage of the game, strategies are optimal given the beliefs, and – whenever possible – the beliefs are obtained from the equilibrium strategies and the observed actions using Bayes' rule. Of course, in equilibrium consumers' beliefs are correct. However, the definition leaves beliefs unrestricted after actions that in equilibrium are not supposed to happen (following a deviation). Since the only way a deviation in investment is observed is when there is a revealing signal, the signal determines the ensuing beliefs. Thus, the only case left is when the consumers observe an unexpected price. In this case, in order to charecterise the maximal set of equilibria, we assume that they come to believe that the firm in question has not invested.[9]

[9] With traceability, this only reflects on the plant of the product's origin, otherwise, in case of monopoly, on both plants.

2.1 Discussion of the model

We have striven to find the levels of complexity and generality that allow for a transparent demonstration of the characteristics and relevance of product differentiation in the CCSR context, withouting expect the model to accurately predict CCSR. In any case, some of our assumptions deserve some discussion.

1. We have assumed variable costs to be the same with both technologies. While in reality a clean good is likely to have higher variable cost as well, the gain in realism does not compensate for the loss in clarity.

2. We have assumed that for a consumer buying a clean good generates "warm glow" but buying a dirty one does not generate "cold sweat". In terms of simplicity, this is just a normalisation. In terms of realism, this captures the idea that using the dirty technology is continuing with the status quo.

3. We have assumed that the consumers evaluate the product they purchase rather than the firm's ethical behaviour. That is, they are adjudicating brownie points to themselves – for having chosen a green product –, rather than to the firm – for being SR. The alternative would have two drawbacks: first, it would need the precise definition of how the firm's behaviour affects the consumers' evaluation of it: how does it depend on the quantities produced of each variety? Is it reasonable to expect that they can estimate these quantities? Second, it would obfuscate the importance of traceability:[10] in fact, for the specific definition – where the firm is evaluated as the expected product (uniformly) randomly chosen form its output – it would be identical to our model without traceability. As the likely truth is that consumers evaluate both the products and the firms to some extent, our approach – highlighting the relevance of traceability – seems more insightful.

[10]It is our belief that transparency with regards to CCSR is not unidimensional. As Woodman (2021) states, "transparency and traceability are distinct and shouldn't be used interchangeably". While it is pertinent for CCSR which technologies a firm uses (or from which suppliers it obtains its input); it is also relevant for consumers that a firm can assure them about the technology a given good was produced with (from which particular supplier it got its input, say, for instance, whether the palm oil used was obtained from a responsible source).

4. The level of investment transparency γ regarding the technology used by the firms is modelled in a rather extreme form: either perfect information or no information whatsoever. This is clearly a simplification of a more realistic manner to model the information structure, one with noisy signals on the technology choice of firms available to agents.

5. We have "normalised" the consumption value at one. Of course, given the fixed (production) cost function, this is not without loss of generality. For example, it implies that a monopolist strictly prefers to sell to all customers whether the good is dirty or clean when w is low. If consumption value was much smaller than 1, it would be optimal for the monopolist (because of its increasing marginal costs) to sell only to a segment of consumers even when prducing with the dirty technology. Again, we think the clarity/generality tradeoff decants towards transparency.

6. We have imposed an upper bound on w to better focus the exposition on the economic insights. For $w > 1.5$, additional equilibria may exist in some cases. Because of the normalization of the consumption value of the good to 1, w measures the relative importance of the warm-glow with respect to the consumption value of the good. Note that with a cap of 1.5 on w we are allowing for 1/3 of the consumers to weigh more heavily the ethical dimension than the consumption value of the good – this is why we do not think the restriction to be excessive.

3 Monopoly

We start our analysis by identifying the M's maximal[11] equilibrium continuation profits following each possible investment strategy, assuming that the monopolist sets her optimal price. In the next subsection we will check under which parameter configurations do equilibria involving these strategies actually exist.

Note that payoffs depend on whether there is product traceability or not; namely, on

[11]Looking at the highest possible continuation payoff gives us the largest set of parameters for which any given investment behavior is supported in equilibrium.

whether the M is able to market the goods produced with different technologies separately. We derive results for both scenarios. In the presence of product traceability, after a mixed investment (investing in the clean technology in one plant but not in the other), she can set two prices and benefit from price discrimination. Otherwise, absent product traceability, following mixed investment consumers are aware that the probability of the good being clean is interior, but a common price is charged.

Proposition 1 *The M's maximal continuation profits (gross of investment costs) in case she invests in two (C), one (CD, if two products; M, if one), or zero (D) plants are, respectively:*

$$\Pi^C = \begin{cases} 3/4, \text{ if } w \leq 1/2 \\ \frac{(1+w)^2}{1+4w}, \text{ if } w \geq 1/2, \end{cases},$$
$$\Pi^{CD} = \frac{3+w}{4},$$
$$\Pi^M = \begin{cases} 3/4, \text{ if } w \leq 1 \\ \frac{2+2w-w^2}{2+4w-2w^2}, \text{ if } w \geq 1, \end{cases}$$
$$\Pi^D = 3/4.$$

Depicting the payoffs in Figure 1, gives us the following corollary.

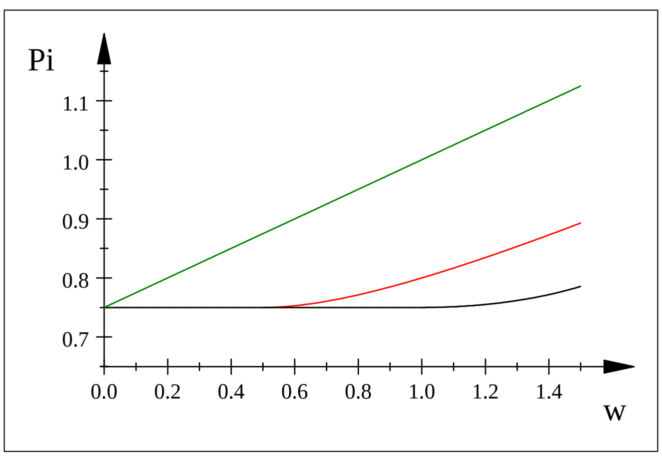


Figure 1

Corollary 1 *The M's maximal equilibrium continuation profits (gross of investment cost) are ranked for all w:* $\Pi^{CD} > \Pi^C \geq \Pi^M \geq \Pi^D$.

Perhaps the only surprising result here is that product differentiation always pays. This is not a fully general result: if the consumption value were low (rather than 1) it could be reversed. However, it is helpful in simplifying our set of equilibria.

3.1 Equilibrium conditions

There are two scenarios, depending on whether the products can be traced. We analyze them in sequence.

3.1.1 With product traceability

When there is product traceability, a monopolist that invests in one plant may set two prices. Let us identify the conditions under which each of the three potential equilibria exist.

(1) We first investigate the existence of the clean equilibrium where the M invests in both plants. If the M deviates to upgrade only one plant and she is caught out by the signal then her continuation profit becomes Π^{CD}. Otherwise, she can continue to earn the equilibrium profit Π^{C} (but enjoy the savings in investment cost). Thus, the deviation is not profitable if and only if $\Pi^{C} - (1+k)F \geq \gamma\Pi^{CD} + (1-\gamma)\,\Pi^{C} - F \Leftrightarrow F/\gamma \leq \frac{\Pi^{C}-\Pi^{CD}}{k}$. As, by Corollary 1, the right-hand side is negative, there is no equilibrium with double investment for any k.

(2) Let us consider now the mixed investment equilibrium (where M invests in one plant) next. What if the M deviates and does not invest at all? With probability γ she is found out and her payoff is Π^{D}. Otherwise, no one notices and she can still earn Π^{CD}.

What if she deviates and invests in both plants? With probability γ she is found out and her payoffs are $\Pi^{C} < \Pi^{CD}$. Otherwise, she continues earning Π^{CD}. This is clearly inferior. Therefore, we have a mixed investment equilibrium if and only if

$$\Pi^{CD} - F \geq \gamma\Pi^{D} + (1-\gamma)\Pi^{CD}. \qquad (1)$$

We thus have the following result.

Lemma 1 *With product traceability, it is an equilibrium that the M invests in one plant if and only if*

$$F/\gamma \leq \Pi^{CD} - \Pi^{D} = w/4. \tag{2}$$

(3) Finally, let us turn to the no investment equilibrium. If the M deviated and invested, then when the consumers did not receive the signal they would consider a higher price a ruse and refuse to buy. Thus, the M would have to charge 1, leading to Π^D despite the extra investment. If the deviation were revealed, she would set the same price and earn the same profit as in the equilibrium with investment, Π^C or Π^{CD}, depending on the deviation. That is, for neither deviation to succeed we need

$$\Pi^D \geq \max\{\gamma\Pi^C + (1-\gamma)\Pi^D - (1+k)F, \gamma\Pi^{CD} + (1-\gamma)\Pi^D - F\} = \gamma\Pi^{CD} + (1-\gamma)\Pi^D - F,$$

where we have used Corollary 1 (and $kF \geq 0$) to derive the equality. Thus, we have the following lemma.

Lemma 2 *With product traceability, it is an equilibrium that the M does not invest at all if and only if*

$$F/\gamma \geq \Pi^{CD} - \Pi^{D} = w/4.$$

Collecting the results of this subsection yields the following unique[12] prediction.

Proposition 2 *With product traceability, the M will invest in only one plant if $F/\gamma \leq w/4$. Otherwise, she does not invest.*

It is immediate that – as expected – higher investment cost, F, and/or lower market transparency, γ, makes sustaining investment in equilibrium more difficult. A higher importance attached by the consumers to CCSR also makes investment more likely.

3.1.2 Without product traceability

When there is no product traceability, it is not possible for the M to supply several varieties: even when consumers know that the M invested in one plant but not in the

[12] Exactly on the boundary, both equilibria exist.

other, it is not possible for them to know in which plant the good was produced. As a consequence, the M can only set one price. We again identify the conditions under which each of the three potential equilibria exist.

(1) We first investigate the existence of the clean equilibrium. If the M deviates to upgrade only one plant and she is caught out by the signal then her continuation profit becomes Π^M. Otherwise, she can continue to earn the equilibrium profit Π^C (but enjoy the savings in investment cost). Thus, the deviation is not profitable if and only if $\Pi^C - (1+k)F \geq \gamma\Pi^M + (1-\gamma)\,\Pi^C - F \Leftrightarrow F/\gamma \leq \frac{\Pi^C - \Pi^M}{k}$.

If the M deviates by not investing at all, when the signal arrives she is discovered. At that point, her continuation payoff is Π^D. When there is no signal, the M can continue to charge p^C, as the consumers do not expect a deviation. Then her gross profits are the same as in equilibrium, but she saves the investment costs. Thus the deviation is not profitable if and only if $\Pi^C - (1+k)F \geq \gamma\Pi^D + (1-\gamma)\,\Pi^C \Leftrightarrow F/\gamma \leq \frac{\Pi^C - \Pi^D}{1+k}$.

These observations lead to the following lemma (proved in the Appendix).

Lemma 3 *Without product traceability, it is an equilibrium that the M invests in both plants if and only if*

$$F/\gamma \leq T^C(k,w) = \begin{cases} 0, \text{ if } w \leq 1/2 \\ \frac{(2w-1)^2}{4(1+k)(1+4w)}, \text{ if } w > 1/2. \end{cases}$$

(2) Let us consider the mixed investment equilibrium next (where the M invests in only one plant). What if the M deviates and does not invest? With probability γ she is found out and her payoff is Π^D. Otherwise, no one notices and she can still earn Π^M.

What if she deviates and invests in both plants? With probability γ she is found out and her payoffs are Π^C. Otherwise, she continues earning Π^M. Thus, we have a mixed investment equilibrium if and only if

$$\Pi^M - F \geq \max\{\gamma\Pi^D + (1-\gamma)\Pi^M, \gamma\Pi^C + (1-\gamma)\Pi^M - (1+k)F\}. \quad (3)$$

As we prove in the Appendix, this condition is never satisfied.

Lemma 4 *Without product traceability, it is not an equilibrium that the M invests in just one plant.*

(3) Finally, let us turn to the no investment equilibrium. If the M deviated and invested, then in the absence of the signal she would continue to earn Π^D. If the deviation were revealed, she would set the same price and earn the same profit as in the equilibrium with investment, Π^C or Π^M, depending on the deviation. That is, for neither deviation to succeed we need

$$\Pi^D \geq \max\{\gamma\Pi^C + (1-\gamma)\Pi^D - (1+k)F, \gamma\Pi^M + (1-\gamma)\Pi^D - F\}.$$

Thus, we have the following lemma.

Lemma 5 *Without product traceability, it is an equilibrium that the M does not invest at all if and only if*

$$F/\gamma \geq T^C(k,w).$$

Collecting the results of this subsection yields the following unique[13] prediction.

Proposition 3 *Without product traceability, the M will invest in both plants if*

$$F/\gamma \leq T^C(k,w) = \begin{cases} 0, \textit{ if } w \leq 1/2 \\ \frac{(2w-1)^2}{4(1+k)(1+4w)}, \textit{ if } w > 1/2. \end{cases}.$$

Otherwise, she does not invest at all.

Logically, when the relevance of the warm-glow is below a cut-off ($w = 0.5$), no matter how low the cost of investment is, it is never an equilibrium for M to invest.

We summarize the comparative statics as a corollary.

Corollary 2 **i)** *Higher economies of scale (lower k) make double investment more likely: $\frac{dT^C(k,w)}{dk} < 0$ whenever $T^C(k,w) > 0$, moreover whether $T^C(k,w) > 0$ is independent of k;*

[13] Again, exactly on the boundary both equilibria exist.

ii) *Higher warm glow, w, makes double investment more likely,* $\frac{dT^C(k,w)}{dw} > 0$ *whenever* $T^C(k,w) > 0$.

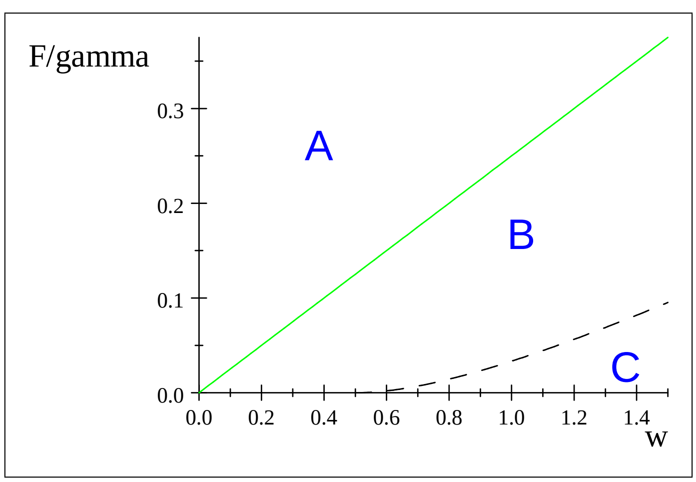
The fact that a higher k is a substitute for a higher F is straightforward, as they multiply each other in the profit function. What is less obvious is that the possibility of the existence of a low enough F/γ so that the double investment equilibrium exists – that is, $T^C(k,w) > 0$ – is independent of the economies of scale present. But actually it results from the same substitutability. For a high k we can always substitute a low enough F, to keep the ranking of payoffs the same.

3.2 Endogenous product traceability

We consider now the situation in which in a period 0, before deciding whether to invest in the Clean technology in either or both factories, the monopolist can choose whether there is product traceability or not. In such a scenario it is not hard to prove the following proposition:

Proposition 4 *It is always optimal for the M to invest in product traceability, provided it is not too costly.*

Proof. The M has to compare her profits of either decision, to invest in PT or not. By Propositions 2 and 3, there are three areas, A, B and C, as shown in the following figure (we have fixed $k = 0.5$ for this figure):



In area A product traceability is irrelevant since in either case the M does not invest in the clean technology.

In area B the M invests in only one factory if there is PT, but it does not to if there is no PT. In this case M has to compare its profits if it chooses to have PT (in which case it will invest in one factory and will be able to price discriminate among its customers), namely $\Pi^{CD} - F = \frac{3+w}{4} - F$, with those if it chooses not to invest in PT (in which case it will not invest in either factory, and only supply the dirty variety), namely, $\Pi^{D} = 3/4$. It is clear that the M will invest in a costless PT if

$$\frac{3+w}{4} - F \geq \frac{3}{4} \Leftrightarrow F \leq \frac{w}{4}.$$

Notice that being in area B requires that $\frac{F}{\gamma} \leq \frac{w}{4}$, that is $F \leq \gamma\frac{w}{4}$. Hence, if $F \leq \gamma\frac{w}{4}$ for $\gamma \leq 1$ it follows that $F \leq \frac{w}{4}$. Thus, in area B it is always optimal for the firm to invest in costless product traceability.

In area C, with PT, M invests in only one factory, while without PT it invests in the clean technology in both factories. M's profits (gross of investment costs) in the former case are Π^{CD}, while in the latter one are Π^{M}. Hence, investing in costless PT pays when

$$\Pi^{CD} - F \geq \Pi^{M} - (1+k)F.$$

From Corollary 1 we know that $\Pi^{CD} > \Pi^{M}$, thus for low enough cost investing in traceability is profitable. ■

The intuition is straightforward: M prefers to be able to price discriminate among its customers according to their heterogenous willingness to pay for the clean product, rather than having to charge a single price to all of them. In order to do that, product traceability is required. This result, however, does not make the analysis of the consequences of the lack of product traceability uninteresting: investing in product traceability might be so costly that the firm chooses not to do so.

Finally, notice that the question on the social optimality of choosing PT is also quite straightforward to answer. Following our basic assumption that the more investments in the clean technology the better (given its large external benefits), it is socially optimal when it induces M to invest (rather than not), and it is not when it induces the firm to move from a double investment to just one.

4 Competition

In this section we move to the duopoly framework, with each firm owning a single production facility, de[icting the situation before a merger. In this situation product traceability is not relevant (for investment incentives); investment transparency on its own gives the full picture. With two firms there are also three types of potential equilibria, depending on the investment decision of each firm: (C, C), (C, D), (and its symmetric counterpart (D, C)), and (D, D). Next, we first characterize the firms' (gross of investment cost) profit functions in each potential equilibrium and, second, in the following subsection, find the conditions under which these investment decisions indeed for part of an equilibrium.

(1) Let us first consider the potential equilibrium where both firms invest in the clean technology, namely, (C, C). As we argued before, the resulting homogeneous-good price competition has many equilibria, but we use the one that leads to the competitive outcome.

In (C, C) consumers expect that both firms have invested, so we have the full aggregate demand function, $p = 1+w(1-Q)$ (for $Q \leq 1$, c.f. Figure A1), while the aggregate supply curve – given $c'(q) = q$ – is $p = Q/2$. Since the latter is always smaller, this means that we have a corner solution, with the whole market being served ($Q = 1$). The competitive price is then $1/2$. Thus, due to the intense competition, firms do not benefit from the extra willingness to pay of the conscientious consumers. This leads to a per firm (gross) profit of:

$$\Pi(C, C) = 1/4 - \frac{1}{2}\left(\frac{1}{2}\right)^2 = 1/8.$$

(2) Next, let us consider the potential asymmetric equilibrium where, say, firm 1 does not invest while firm 2 does, namely, (D, C). The framework, then, is one of a differentiated-goods duopoly. We prove the following result in the Appendix.

Lemma 6 *In an equilibrium where only one firm invests, the gross equilibrium payoffs are*

$$\Pi(D, C) = \frac{(1+w)^2(1+2w)}{2\,(2+3w)^2}$$

and

$$\Pi(C,D) = \frac{(1+2w)^3}{2\,(2+3w)^2},$$

for the dirty and clean firm, respectively.

(3) Finally, let us consider the potential equilibrium-scenario where neither firm invests in the clean technology, namely, (D,D). In that case consumers are not willing to pay more than 1. Thus, the aggregate demand is 1 for all $p \leq 1$. Aggregate supply is again $Q/2$, resulting in a price of $1/2$. It is straightforward to compute each firm's (gross) competitive profits in this scenario:

$$\Pi(D,D) = \frac{1}{4} - \frac{1}{2}\left(\frac{1}{2}\right)^2 = \frac{1}{8}.$$

Notice that these are the same (gross) expected profits as in competition with both firms investing in the clean technology.

Lemma 7 *The firms' equilibrium continuation profits (gross of investment cost) are ranked for all* $w > 0$*:* $\Pi(C,C) > \Pi(C,D) > \Pi(D,C) > \Pi(D,D)$*.*

4.1 Equilibrium conditions

Next, we derive the conditions under which each of the above potential equilibria exist. Recall that, in a (Perfect Bayesian) Nash equilibrium, consumers take as given the investment decisions of firms; however, if they observe that a firm deviated from the equilibrium strategies, consumers update their beliefs accordingly. Unexpected prices can also lead to a belief revision, just as in the case of monopoly. We will address this issue when it arises.

(1) Let's start by characterizing the conditions under which investing in the clean technology by both firms is part of an equilibrium; namely, the (C,C) one. This is an equilibrium when it is not optimal for either firm to deviate unilaterally. To calculate the deviation payoffs, assume firm 1 deviates and does not invest. With probability γ, the consumers (and the competitor) learn about the deviation, in which case the competition between firms will take place according to the differentiated goods model, giving the

deviator a payoff of $\Pi(D, C)$. With probability $1-\gamma$ the deviation is not observed, thus, consumers (and the competitor) stick to their beliefs that the firm did invest. Then, it is best for the deviant firm to stick to charging the (C, C) equilibrium price (independent of the off-equilibrium beliefs, as the variable costs are the same with and without investment). Accordingly, (C, C) is an equilibrium if and only if

$$\Pi(C, C) - F \geq \gamma \Pi(D, C) + (1-\gamma)\Pi(C, C),$$

namely, the net profit for firm 1 of investing in the clean technology is larger than the expected profit of not doing so, given that firm 2 invests. Simplifying, we obtain that (C, C) is an equilibrium when[14]

$$F/\gamma \leq T_C(w) := \Pi(C, C) - \Pi(D, C).$$

(2) Let us turn now to the potential equilibrium where firm 1 invests while firm 2 does not, namely, (C, D). This is an equilibrium if the following two conditions hold:

$$\begin{aligned} \Pi(C, D) - F &\geq \gamma \Pi(D, D) + (1-\gamma)\Pi(C, D), \\ \Pi(D, C) &\geq \gamma \left[\Pi(C, C) - F\right] + (1-\gamma)\left[\Pi(D, C) - F\right]. \end{aligned}$$

If firm 1 deviates and does not invest, with probability γ this is observed by consumers (and the other firm), implying they compete as in (D, D); with probability $1-\gamma$ nobody observes the deviation and thus competition takes place as in (C, D).[15] Similar arguments lead to the no-deviation condition for the firm that is not supposed to invest in equilibrium.[16] Simplifying the above expressions, we obtain, respectively:

$$\begin{aligned} F/\gamma &\leq T_D(w) := \Pi(C, D) - \Pi(D, D), \\ F/\gamma &\geq T_C(w). \end{aligned}$$

[14] Obviously, the same constraint results considering firm 2's deviation.

[15] Again, it is not in the interest of the deviator to charge a different price that would potentially reveal the deviation.

[16] Just as in case of the monopoly, in order to find the largest set of parameters for which the equilibrium exists, we assume the harshest beliefs off the equilibrium path. We assume that charging the high price would not convince the consumers that investment has taken place. Thus, in the absence of a revealing signal the deviator will price as if she had not invested.

Note that the conditions that keep the firms from switching between (C, C) and (D, C) are exactly complementary – modulo the overlap at the boundary. Clearly, the conditions for the (D, C) equilibrium are exactly the same.

(3) Finally, neither firm investing in the clean technology, (D, D), is an equilibrium if and only if the following condition holds (neither firm wants to deviate by investing):

$$\Pi(D, D) \geq \gamma\Pi(C, D) + (1-\gamma)\Pi(D, D) - F,$$

simplifying yields

$$F/\gamma \geq T_D(w).$$

Yet again, the conditions that keep the firms from switching between (C, D) and (D, D) are complementary.

Observing that by Lemma 7, $T_D(w) > 0 > T_C(w)$, for $w > 0$, we have the following proposition.

Proposition 5 *The equilibrium where both firms invest does not exist. The boundary between (D, D) and (C, D) is $F/\gamma = T_C(w) = \frac{(1+2w)^3}{2(2+3w)^2} - 1/8$.Namely, (D, D) is the equilibrium when $F/\gamma \geq T_C(w)$, while (C, D) is the equilibrium when $F/\gamma \leq T_C(w)$.*

5 Comparing monopoly with duopoly

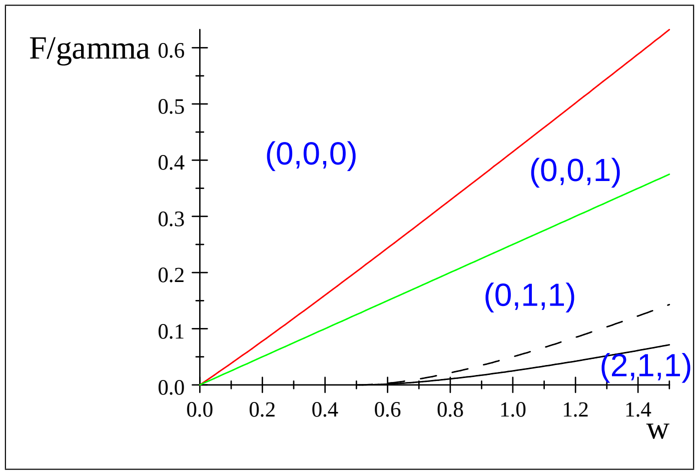
Armed with the full characterization of equilibria both for monopoly and for duopoly, we can now compare the effects of the different market structures on CCSR, namely, which one leads to more investment in the clean technology.

Theorem 1 i) *When* $F/\gamma \leq T^C(k, w) = \begin{cases} 0, \text{ if } w \leq 1/2 \\ \frac{(2w-1)^2}{4(1+k)(1+4w)}, \text{ if } w > 1/2. \end{cases}$*, under competition and under differentiated monopoly there is a single investment, while under non-differentiated monopoly there is double investment .*

ii) *When $F/\gamma \in \left[T^C(k, w), w/4\right]$, under competition and under differentiated monopoly there is a single investment, while under non-differentiated monopoly there is no investment.*

iii) *When* $F/\gamma \in \left[w/4, T_C(w) = \frac{(1+2w)^3}{2(2+3w)^2} - 1/8\right]$, *under competition there is a single investment, while under monopoly there is no investment.*

iv) *When* $F/\gamma > T_C(w)$, *there is no investment.*



The top line is $T_C(w)$, *the next is* $w/4$, *followed by* $T^C(0, w)$ *and* $T^C(1, w)$. *The vectors show the number of investments in monopoly without traceability, monopoly with traceability, and duopoly, respectively.*

The results show a nuanced effect of market structure on CCSR. Depending on the level of investment transprency (F/γ) and the feasibility of traceability, either market structure can be socially optimal. However, when there is enough market transparency (both investment transparency and product traceability), then competition weakly dominates monopoly. Let's explain why. When there is product traceability, competition is never inferior to monopoly: either both of them lead to the same outcome (if F/γ is low, one investment, if it is high no investment) or competition is superior (when F/γ is intermediate, competition leads to investment, while monopoly does not).

Without traceability, instead, for low F/γ there is double investment with monopoly but only single investment with competition; the lack of traceability prevents the M from price discrimination making it profitable when F/γ is small to invest in both factories. At the same time, for intermediate F/γ we have competition dominating, as in the case of traceability. It is worth noting that the possibility of higher investment for low F/γ introduced by the lack of traceability, does have a flip side: it increases (relative to the case with traceability) the space of values of F/γ and w for which competition strictly dominates monopoly.

Notice then that CCSR is monotonic in investment transparency γ and on consumers' willingness to pay for clean goods w. But it is not monotonic in product transparency since the absence of product traceability might increase CCSR (since it prevents price discrimination).

Finally, our framework also allows us to study the interaction between competition and market transparency, and we show this is indeed much nuanced. On the one hand, with a duopoly, when there is product traceability, the level of investment transparency required so as to induce a higher level of investment is smaller. On the other hand, however, with a monopoly and absent product traceability, if the level of investment transparency is large, then investment in the clean technology can be maximized.

6 Concluding remarks

While the impact of market competition on firms' green investments is crucial in the current debate on the role of antitrust in the Green New Deal in the EU and the US, the theoretical evidence is mixed. While the empirical analysis to a large extent supports the view of competition having a positive effect on CSR, theoretical analysis is ambiguous in its results (Aghion et al., 2021, and Calveras and Ganuza, 2016, for instance, provide opposing results). It is therefore important to isolate nuances in the market that can determine the appropriate antitrust approach for authorities focused on sustainability and environmental performance.

Our analysis highlights a key dimension of sustainable consumption and production, its characteristic as a credence attribute. The a priori unobservability of CCSR implies that market transparency is paramount. We consider that there are two dimensions to market transparency: (i) investment transparency: credible signals about the technology/ies a firm uses; (ii) product traceability: proof of the procedence of the good (at the plant level). Both of these turn out to be relevant for assessing the effect of market competition on incentives for CCSR and green investments.

Our main results can be summarized as follows. With product traceability, competition makes it more likely for firms to invest in green technologies; in other words, the level of market transparency required for one firm/plant to switch to green technology is smaller under a duopoly than with a monopoly.[17] This is the opposite prediction to that of Calveras and Ganuza (2016) in which more intense market competition reduces CSR. Such a difference lies in the definition and modeling of competition: while they consider the effect of an increase in competition in the SR segment (which reduces mark-ups and profits of CCSR) in a framework in which there is a competitive fringe of dirty firms that get zero profits, we only observe the impact on CCSR of moving from a monopoly (with two factories) to a duopoly (and not market structures with more intense competition). Though this might seem more limited, our framework makes fully endogenous all firms' technology choice, thus allowing for the presence of more nuanced effects such as the incentives for product differentiation, both in the monopoly as well as in the duopoly. Moreover, we incorporate in the discussion the key role of product traceability, not present in Calveras and Ganuza (2016). Aghion et al. (2020) also show the positive effect of market competition on green investment as a way to 'escape competition' (i.e., product differentiation); unlike them, our analysis incorporates the key role of market transparency and fully endogenises CCSR by allowing all firms to invest (or not).

Absent product traceability, the results differ, showing again the key role of transparency in the analysis. A highly transparent monopolist would switch all her plants to the green technology. In a duopoly, instead, only one firm would invest in the green technology. Thus, monopoly might lead to higher investments in CCSR.

Driving our results is the push in markets towards product differentiation; and the fact that such a push is stronger under competition (in a duopoly) than with a monopolist, and the fact that without product traceability price discrimination by the monopoly is not possible. Such a push towards product differentiation has two sides. On the one hand, it provides incentives toward green investments. On the other hand, it might also set a limit to the amount of green investment to be expected in the market. A firm with

[17]Equivalently, for a given level of market transparency, competition allows investment to occur for higher costs than in monopoly.

a green competitor might prefer to supply the dirty variety precisely to differentiate its product, even if most consumers show a significant willingness to pay for green goods. A monopolist might also prefer to supply both product varieties so as to be able to price discriminate and charge a higher price to ethical consumers. In either case this limit to CSR would provide a rationale for regulatory interventions (such as, for instance, setting technology standards) alongside the workings of market and firm incentives for social responsibility.

6.1 Antitrust and the green economy

The current debate on antitrust in the green economy questions whether there is a rationale for restricting competition so as to incentivize companies to jointly take more sustainability initiatives. A more lax antitrust approach, allowing horizontal agreements among firms regarding green or ethical dimensions, would bolster green initiatives and investments, goes one side. Schinkel and Treuren (2021a) provide a non-technical summary of the debate and evidence, stating that there is little or no ground in economics for such a more lax approach (see also Schinkel and Treuren, 2021b; and Schinkel and Spiegel, 2017).

While our results overall provide evidence of the importance of competition in fostering green investments where, under a monopoly, they might not take place, they also provide a possible rationale whereby firm horizontal agreements might in some cases turn out to be positive. In particular, in markets where firms want to differentiate their products in their green attributes, horizontal agreements among firms might allow them to coordinate their investments and thus efficiently advance green investments. This is not a general result; the social advantage of a horizontal agreement would appear when at a market with competition and product differentiation, the profit of the firm that invests in the green technology is smaller than that which keeps using the dirty one, though both prefer a market with differentiated products. In such a case, coordinating investments with the corresponding compensating side transfers among firms might foster green investments and be welfare improving.

Appendix

Proof of Proposition 1. Suppose first that the M upgrades both plants in equilibrium. In that case, the consumers will always have the posterior that she has invested in both: when they receive the signal they have proof, while otherwise they have no reason to believe that she has deviated, since they are supposed to be "in equilibrium". Note, however, that – since off the equilibrium path players' beliefs are unrestricted by PBE – in the absence of a signal, the consumers could threaten to switch their belief about the technology if the price differed from the one they had expected in equilibrium. In principle, this could give rise to a multitude of possible equilibrium prices, where the consumers' off-path expectations "force" a price on the M. The maximal equilibrium continuation is given by the seller-optimal clean price, as product/price differentiation is not compatible with the double investment equilibrium.[18]

As a result, the (inverse) demand facing the M is $p = 1 + w(1 - Q)$ whether or not there is a public signal, where $Q \in [0, 1]$ is the total quantity sold.

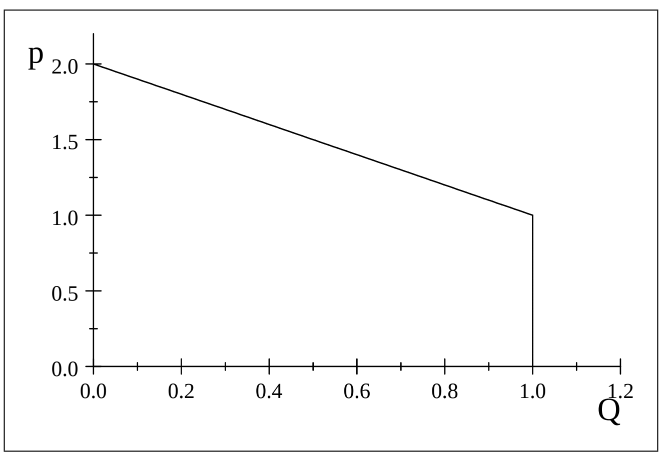


Figure A1: The demand when $w = 1$ and consumers believe the technology is clean.

Then, revenue is $R(Q) = (1+w(1-Q))Q$ and marginal revenue is $R'(Q) = 1+w(1-2Q)$. Marginal cost results from the efficient (symmetric) distribution of production across the two plants: $c_2(Q) = 2c(Q/2)$, implying that $c_2'(Q) = Q/2$. Unless $R'(1) > c_2'(1)$ – that is, unless $1 - w > 1/2$ – an interior solution is guaranteed (otherwise, all the consumers

[18]Consumers can only vary their beliefs following an observed deviation.

buy at price 1, and the M is happy to serve them all as $c_2'(1) = 1/2$ is less than the price, 1). The optimal quantity is that for which $c_2'(Q) = R'(Q)$. Solving, we find that $Q^C = \frac{2(1+w)}{1+4w}$. Then $p^C = 1 + w\left(1 - Q^C\right) = 1 + w\frac{1-2(1-w)}{1+4w} = \frac{(1+w)(1+2w)}{1+4w}$ and consequently gross monopoly profits following double investment are

$$\Pi^C = \begin{cases} \frac{(1+w)(1+2w)}{1+4w}\frac{2(1+w)}{1+4w} - \frac{1}{4}\left(\frac{2(1+w)}{1+4w}\right)^2 = \frac{(1+w)^2}{1+4w}, \text{ if } w \geq 1/2 \\ 1 - 1/4 = 3/4, \text{ if } w < 1/2. \end{cases}$$

Next, consider the hypothetical equilibrium without investment. As the consumers expect the technology to be dirty, the M can only charge 1 (the highest price consumers accept in the absence of clean technology). Again the M would not want to ration. Thus, the hypothetical equilibrium profit is the same as the corner solution with double investment,

$$\Pi^D = 3/4.$$

The third type of potential equilibrium is the mixed one, where the M produces one product with clean technology and one with the dirty one. In this case, to maintain comparability with duopoly, we assume that the signal is accurate on both plants/products with probability γ (and with the remaining probability no signal is issued). We treat the case where the consumers know which plant the good was produced in first.

In this equilibrium, if the signal arrives and the M sets prices p_C^{CD} and $p_D^{CD} = 1$, the indifferent consumer is $\theta^* = \frac{p_C^{CD}-1}{w}$, so the respective demands will be $q_C^{CD} = 1 - \frac{p_C^{CD}-1}{w}$ and $q_D^{CD} = \frac{p_C^{CD}-1}{w}$.[19] Thus, the M maximizes

$$\frac{1+w-p_C^{CD}}{w}p_C^{CD} - \frac{\left(1+w-p_C^{CD}\right)^2}{2w^2} + \frac{p_C^{CD}-1}{w} - \frac{\left(p_C^{CD}-1\right)^2}{2w^2}.$$

The first-order condition becomes

$$\left(2 + w - 2p_C^{CD}\right)(w+1) = 0,$$

so $p_C^{CD} = \frac{2+w}{2}$. As a result, $\theta^* = 1/2$ and the M shares production efficiently – that is, equally – between the plants, $q_D^{CD} = q_C^{CD} = 1/2$.[20]

[19]Note that again the M is happy to satisfy all the demand.

[20]Of course, this is not a general result but follows from the linearity assumed.

If no signal arrives then, the maximal continuation profits again result when the equilibrium prices are the same as when the signal arrives.

Consequently, the maximal hypothetical equilibrium (gross) profits will be

$$\Pi^{CD} = \frac{2+w}{4} - 1/8 + 1/2 - 1/8 = \frac{3+w}{4}.$$

Finally assume that we are in the mixed investment equilibrium but the product cannot be differentiated according to its origin. Then the M has to charge a single price in equilibrium. The consumers will believe that the good is clean with probability $\frac{q_1}{Q}$, where q_1 is the equilibrium quantity produced by the clean technology and Q is the total quantity sold. As a result, the (inverse) demand facing the M is $p = 1 + \frac{q_1}{Q}w(1-Q)$ whether or not there is a public signal. Then the M's problem is

$$\max_{q_1,q_2} Q + q_1 w(1-Q) - \frac{q_1^2+q_2^2}{2} \text{ s.t } Q \leq 1, q_2 \geq 0,$$

where we are taking for granted that she will produce at the clean plant (otherwise, she would not want to invest in it). The Lagrangian becomes

$$\begin{aligned} 1 + w(1-Q-q_1) - q_1 + \lambda + \mu &= 0 \\ 1 - wq_1 - q_2 + \lambda + \mu &= 0 \end{aligned}$$

with complementary slackness conditions

$$\lambda (1-Q) = 0 \text{ and } \mu q_2 = 0.$$

We have four cases to consider.

Case I $\lambda = \mu = 0$ (neither constraint binds)

Solving the FOCs we obtain

$$q_1 = \frac{1}{1+w(2-w)} \text{ and } q_2 = \frac{1+w(1-w)}{1+w(2-w)}.$$

The constraints imply that this solution applies only if $w \in \left[1, \frac{1+\sqrt{5}}{2}\right]$.

Case II $\lambda > 0, \mu = 0$. $(Q = 1)$

Now the FOCs become

$$1 - wq_1 - q_1 + \lambda = 0$$
$$q_1 - wq_1 + \lambda = 0,$$

implying that $q_1 = q_2 = 1/2$. $\lambda > 0$ requires $w < 1$.

Case III $\mu > 0, \lambda = 0$ $(q_2 = 0)$

Now the FOCs become

$$1 + w(1 - 2q_1) - q_1 + \mu = 0$$
$$1 - wq_1 + \mu = 0,$$

implying that $q_1 = \frac{1+w}{1+2w}$ and $\mu = \frac{w^2-1-w}{1+2w}$. $\mu > 0$ requires $w > \frac{1+\sqrt{5}}{2} > 1.5$ what is ruled out by assumption.

Case IV $\lambda > 0, \mu > 0$ $(q_1 = 1, q_2 = 0)$

This case leads to a contradiction.

Consequently gross monopoly profits following mixed investment are

$$\Pi^M = \begin{cases} 1 - 1/4 = 3/4, \text{ if } w < 1 \\ \left(1 + \frac{w}{2+w(1-w)} \cdot \frac{w-1}{1+w(2-w)}\right) \frac{2+w(1-w)}{1+w(2-w)} - \frac{1}{2}\left(\frac{1}{1+w(2-w)}\right)^2 - \frac{1}{2}\left(\frac{1+w(1-w)}{1+w(2-w)}\right)^2 = \\ \frac{3+2w(2-w)(2+w(1-w))-(1+w(1-w))^2}{2(1+w(2-w))^2} = \frac{2+2w-w^2}{2+4w-2w^2}, \text{ if } w \geq 1. \end{cases}$$

■

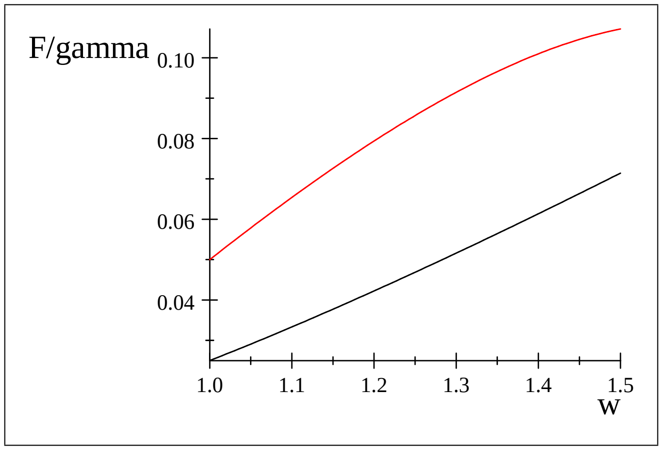
Proof of Lemma 3. From the preceding discussion it follows that we need

$$F/\gamma \leq \min\left\{\frac{\Pi^C - \Pi^D}{1+k}, \frac{\Pi^C - \Pi^M}{k}\right\}.$$

Substituting in for the gross profits, we obtain

$$F/\gamma \leq \begin{cases} 0, \text{ if } w \leq 1/2 \\ \frac{\frac{(1+w)^2}{1+4w} - 3/4}{1+k}, \text{ if } w \in [1/2, 1] \\ \min\left\{\frac{\frac{(1+w)^2}{1+4w} - 3/4}{1+k}, \frac{\frac{(1+w)^2}{1+4w} - \frac{2+2w-w^2}{2+4w-2w^2}}{k}\right\}, \text{ if } w \geq 1. \end{cases}$$

Depicting the two terms of the third line for $k = 1$, and observing that the second term grows faster as k decreases, shows that the first term is always smaller.



Bringing the expression to a common denominator completes the proof. ■

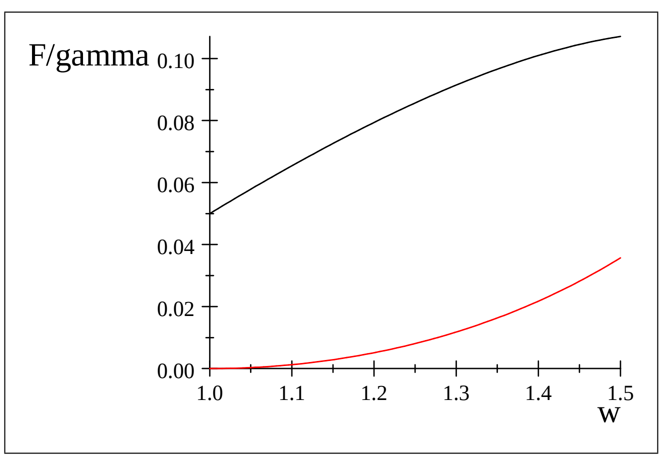
Proof of Lemma 4. From the preceding discussion, the equilibrium exists, if and only if

$$\frac{\Pi^C - \Pi^M}{k} \leq F/\gamma \leq \Pi^M - \Pi^D.$$

or

$$\left.\begin{array}{c} 0, \text{ if } w \leq 1/2 \\ \frac{\frac{(1+w)^2}{1+4w} - 3/4}{k}, \text{ if } w \in (1/2, 1) \\ \frac{\frac{(1+w)^2}{1+4w} - \frac{2+2w-w^2}{2+4w-2w^2}}{k}, \text{ if } w \geq 1. \end{array}\right\} \leq F/\gamma \leq \left\{\begin{array}{c} 0, \text{ if } w \leq 1 \\ \frac{2+2w-w^2}{2+4w-2w^2} - 3/4, \text{ if } w \geq 1. \end{array}\right.$$

When $w \leq 1$, the equilibrium clearly cannot exist. When $w > 1$, we depict the two values for $k = 1$ (yielding the smallest lower bound):



As the upper bound is smaller than the lower bound, there is no value of F/γ satisfying both inequalities. ■

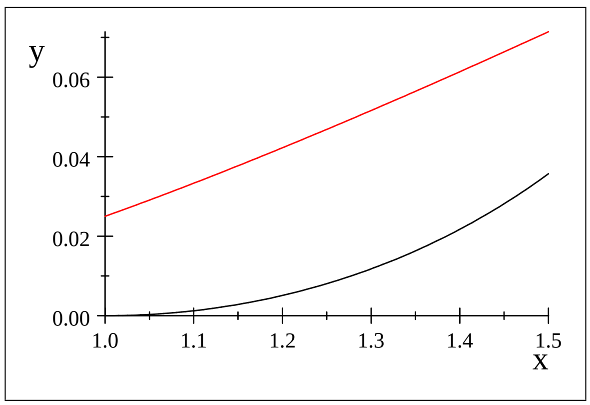
Proof of Lemma 5. From the preceding discussion we have the equilibrium if and only if

$$F/\gamma \geq \max\left\{\Pi^M - \Pi^D, \frac{\Pi^C - \Pi^D}{1+k}\right\},$$

or

$$F/\gamma \geq \begin{array}{c} 0, \text{ if } w \leq 1/2 \\ \frac{(2w-1)^2}{4(1+k)(1+4w)}, \text{ if } w \in (1/2, 1) \\ \max\left\{\frac{2+2w-w^2}{2+4w-2w^2} - 3/4, \frac{(2w-1)^2}{4(1+k)(1+4w)}\right\}, \text{ if } w \geq 1. \end{array}$$

Depicting the two values of the third line for $k = 1$ (the smallest value of the second term) we still obtain that the relevant deviation is to double investment.



■

Proof of Lemma 6. Given that firm 2 is charging p_2, the residual demand curve facing (dirty) firm 1 is kinked: $p_1 = p_2 - wq_1$, for $p_1 \leq 1 \Leftrightarrow q_1 \geq \frac{p_2-1}{w}$, otherwise it is constant at 1.[21] This leads to a discontinuous marginal revenue function that is $p_2 - 2wq_1$ for $q_1 \geq \frac{p_2-1}{w}$, and constant at 1 otherwise, see Figure A2.

[21] To see this, note that the indifferent consumer has $\theta_i = q_1 = \frac{p_2-p_1}{w}$ for $p_1 \leq 1$.

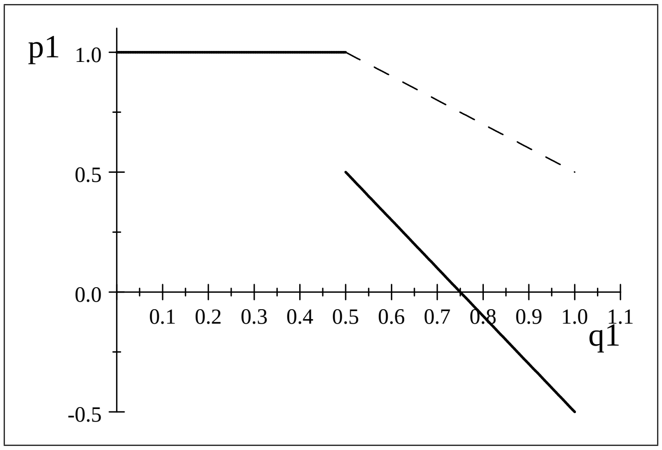


Figure A2: The marginal revenue curve of the dirty firm ($p_2 = 1.5$, $w = 1$)

Equating marginal cost with marginal revenue, the optimal quantity produced when the (clean) competitor charges p_2 is

$$q_1(p_2) = \begin{cases} 1, \text{ if } \frac{p_2-1}{w} \geq 1 \Leftrightarrow p_2 \geq 1+w \\ \frac{p_2-1}{w}, \text{ if } p_2 \in \left[\frac{1+2w}{1+w}, 1+w\right] \\ \frac{p_2}{1+2w}, \text{ if } \frac{p_2-1}{w} \leq 2-p_2 \Leftrightarrow p_2 \leq \frac{1+2w}{1+w}. \end{cases}$$

Substituting into the residual demand, this leads to the optimal best response function

$$p_1(p_2) = \begin{cases} 1, \text{ if } p_2 \geq \frac{1+2w}{1+w} \\ \frac{(1+w)p_2}{1+2w}, \text{ if } p_2 \leq \frac{1+2w}{1+w}. \end{cases}$$

The clean firm 2's residual demand in turn is $p_2 = p_1 + w(1-q_2)$.[22] This leads to the marginal revenue function $p_1 + w(1-2q_2)$, so the resulting optimal quantity is $q_2(p_1) = \frac{w+p_1}{1+2w}$, and – substituting this into the residual demand function – the best response function is

$$p_2(p_1) = \frac{(1+w)(w+p_1)}{1+2w}.$$

Solving the system of equations resulting from the two best response functions, we obtain the equilibrium prices

$$p_1 = \begin{cases} 1, \text{ if } (1+2w)^2 \leq (1+w)^3 \\ \frac{(1+w)^2}{2+3w}, \text{ if } (1+2w)^2 > (1+w)^3 \end{cases} \quad \text{and} \quad p_2 = \begin{cases} \frac{(1+w)^2}{1+2w}, \text{ if } (1+2w)^2 \leq (1+w)^3 \\ \frac{(1+w)(1+2w)}{2+3w}, \text{ if } (1+2w)^2 > (1+w)^3. \end{cases}$$

[22] To see this, note that the indifferent consumer has $\theta_i = 1 - q_2 = \frac{p_2-p_1}{w}$ for $p_1 \leq 1$.

For $w < 1.5$, the condition for the first line is never satisfied. Noting that $p_2 \leq \frac{1+2w}{1+w}$, we can thus directly compute the profits for the dirty firm

$$\Pi(D,C) = \frac{(1+w)^2}{2+3w}\frac{1+w}{2+3w} - \frac{1}{2}\left(\frac{1+w}{2+3w}\right)^2 = \frac{(1+w)^2(1+2w)}{2\left(2+3w\right)^2}$$

and for the clean firm

$$\Pi(C,D) = \frac{(1+w)(1+2w)}{2+3w}\frac{w+\frac{(1+w)^2}{2+3w}}{1+2w} - \frac{1}{2}\left(\frac{w+\frac{(1+w)^2}{2+3w}}{1+2w}\right)^2 = \frac{(1+2w)^3}{2\left(2+3w\right)^2}.$$

■

Proof of Proposition ??.

$$T_D(w) = \frac{(1+2w)^3}{2\left(2+3w\right)^2} - 1/8.$$

To see that it is always positive, note that when $w = 0$ it is equal to zero, while it is increasing in w.

$$T_C(w) = 1/8 - \frac{(1+w)^2(1+2w)}{2\left(2+3w\right)^2}$$

To see that it is always negative, note that when $w = 0$ it is equal to zero, while it is decreasing in w. ■

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