Green Premium, Ecolabel, and Environmental Damage

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Abstract

In markets where differences in environmental performance of competing firms arise due to differences in technology and other attributes that cannot be altered in the short run and firms have private information about these attributes, an ecolabel may allow firms to credibly communicate their private information to environmentally conscious uninformed consumers. This may ameliorate the distortion in pricing and consumption patterns in the market outcomes, when there is no credible direct disclosure mechanism and pricing is the only channel of signaling private information. In an incomplete information duopoly market with price competition, I show that even if a credible ecolabel is available freely, clean firms may not always find it individually advantageous to adopt the ecolabel. The adoption of the ecolabel by the clean firms removes price and welfare distortions (caused by price signaling); in this case, the availability of the ecolabel makes competition more intense, reduces market power, increases market shares of the clean firms, and lowers the expected environmental damage. The effect of the ecolabel on the incentives to invest in the development of a clean technology is more complex.

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1 Introduction

Consumers' willingness to pay a *green premium* for the goods produced with lower environmental damage[1] can, in principle, play an important role in creating market incentives for firms to reduce the environmental damage caused by their production process and thus, foster voluntary compliance. An important barrier to the effectiveness of the green premium is that buyers are very unlikely to be able to directly observe attributes of a product that are relevant to its environmental impacts, such as the production technology and the nature of inputs used in the current production process. In fact, firms are more likely to have private information about these attributes. Ecolabels[2] (and other third party certification mechanisms) are instruments that can be used by the environmentally cleaner firms to credibly and voluntarily disclose their private information to the conscious buyers in order to shift and increase the demand for their own product. While the number of firms and industries where ecolabels have been adopted has increased rapidly in recent years, there are a large number of markets where firms do not appear to be adopting ecolabels (or other means of credible voluntary disclosure)[3]. This, however, does not mean that the environmentally conscious buyers necessarily make an uninformed purchase decisions in such markets. Market behavior of firms such as their pricing decisions may indirectly signal hidden information about current production technology and cost structure and this, in turn, can convey information about the environmental performance of firms to buyers[4]. One should therefore view the adoption of ecolabels (and other means of direct disclosure) as an alternative to communicating information through market based signaling to buyers with green consciousness. The difference between the efficacy of these alternative channels of communication may not lie so much in the information conveyed to buyers as in the way they affect competition, prices, market shares, and profits of different types of firms.

[1] The recent theoretical literature in environmental economics considers environmental friendliness as a vertical attribute of a product and shows that environmentally conscious (green) consumers pay a price premium for an environment-friendly product (see Cremer and Thisse (1989), Arora and Gangopadhyay (2003), Bansal and Gangopadhyay (2003)). Teisl et al. (2002) find that introduction of "dolphin-safe" labels increases the market share of canned tuna. Galarraga and Markandya (2004) show that consumers in the UK pay significant price premium for organic and fair trade coffee. Casadesus-Masanell et al. (2009) find that consumers are willing to pay more for sportswear made of organic cotton that involves lower use of pesticides and fertilizers.

[2] Examples of ecolabels include Energy Star (US), EPA Lead Certification (US), Green-e Energy (US), Eco3Home (US), Agriculture Biologique (EU), Blue Angel (Germany), EU Ecolabel (EU), Swan (Nordic Countries) etc.

[3] According to ecolabelindex.com, a comprehensive online directory of ecolabels, to date there are 465 ecolabels across 25 different industries in 199 countries. There are 148, 74, 22, and 19 ecolabels in the food, electronics, carbon, and water industry respectively. Among the major economies, the US and EU have 203 and 237 ecolabels whereas China and India have 58 and 31 ecolabels respectively.

[4] Hwang et al. (2005) find that consumers use price as a signal of the quality of genetically modified food (corn, bread, and egg).

This paper has two objectives. The first objective is to analyze the strategic incentive of a competing firm to adopt a credible ecolabel to disclose private information about how green its current production technology is when the firm can also signal the same information through pricing. This can help us to understand some of the factors behind why ecolabels are more likely to be prevalent in certain kinds of markets than others. Secondly, this paper attempts to understand how, by moving away from a pure signaling based equilibrium, adoption of an ecolabel can affect market allocation, the extent of environmental damage, and eventually the long run incentive to invest in cleaner technology.

The existing literature on ecolabels has highlighted the role of ecolabels in allowing cleaner firms to credibly disclose hidden information or actions (such as abatement) to buyers, and to focus on this role, the literature generally uses a framework where clean firms have no way to credibly convince consumers about their types or actions if they do not adopt ecolabels or if no ecolabels are available[5]. As mentioned above, this ignores the fact that buyers can make inferences about the cost structure and therefore, the underlying nature of production technology of firms from prices and other market variables chosen by firms. In principle, the market signaling mechanism can be as effective as direct disclosure in informing uninformed buyers. This paper builds on a small literature[6] that focuses on the role of signaling (for instance, through prices) in communication of information about the environmental impact of production technology to potential consumers to study the trade-off between ecolabels and price signaling in order to understand the strategic incentives for adoption of ecolabels by competing firms[7]. In my framework, a firm may choose not to adopt an ecolabel and find it profitable to signal via prices even if there is a credible ecolabel available at a negligible cost. In order to focus on the role of ecolabels[8] and prices in conveying hidden information, I abstract from issues related to current actions of a firm being unobservable,

[5] In this context, it is important to understand that ecolabel resolves asymmetric information problems, namely moral hazard (hidden performance) as well as adverse selection (hidden type) (see Crampes and Ibanez (1996), Kuhn (1999), Mason (2006), and Ibanez and Grolleau (2008)). Fischer and Lyon (2014, 2015) and Li and Veld (2015) focus on the competition among multiple ecolabels that are essentially designed to reveal more information about the nature and degree of the abatement effort by the polluting firms.

[6] See, among others, Sengupta (2015) .

[7] In the standard product quality literature in industrial organization, Janssen and Roy (2015) analyze why strategic competition motivates firms to signal their respective product quality via prices even when the cost of voluntary disclosure is negligible.

[8] A strand of literature in environmental economics critically analyzes the effectiveness of ecolabel as a pollution control instrument (See Kuhn (1999), Matto and Singh (1994) and Dosi and Moretto (2001)). Amacher et. al. (2004) examine whether firms have incentive to invest in abatement technology to be able to qualify for and retain an ecolabel in the absence of any asymmetric information between competing firms and environmentally conscious consumers. In particular, they find that the nature of cost differentials determine whether firms invest in cleaner technology and adopt ecolabel; however, unlike the present paper an ecolabel is not implemented to resolve any incomplete information problem among firms and consumers.

by assuming that a firm cannot alter its production process in the short run in order to affect its environmental impact, and that its long run investment in making the production process cleaner is observable to all (though the final outcome is not).

In particular, I consider an imperfectly competitive industry where two firms compete in prices. All consumers are environmentally conscious and are willing to pay more for the product produced with a technology that causes lower environmental damage. The production technology of a firm can be of two potential types, *dirty* and *clean*. All firms are initially endowed with a dirty production technology and may invest in the development of a cleaner one where the outcome of the investment i.e., whether the realized production process is clean or remains dirty, is intrinsically uncertain[9]. The latter may reflect uncertainty about the success of the project or the environmental impact of the new technology. Investment is observed publicly but not the realized technology. In the next stage, firms choose prices and (clean) firms decide whether to adopt an ecolabel to disclose their actual environmental performance; here disclosure of the type through the ecolabel is assumed to be fully credible. Buyers update their beliefs about the true type of firms' production processes by observing the ecolabel and/or the prices charged before making their purchase decisions.

I find that *the clean firms adopt an ecolabel to credibly disclose their types only when the green premium (that the buyers are willing to pay) is significantly high.* If the green premium is low relative to the production cost advantage of the dirty technology, an ecolabel is not adopted by the clean firms (even if the cost of adopting ecolabels is negligible). This is because a clean type firm with an ecolabel continues to be at a competitive disadvantage when the rival is of the dirty type and thus, focuses on Bertrand like aggressive competition with a rival of the clean type which, in turn, eliminates the rent necessary to cover the cost of adopting the ecolabel. In particular, when the green premium is below a threshold, the market outcome is one where only prices signal the true types of the firms to buyers and the clean firms engage in the marginal cost pricing while the dirty firms earn positive profit and randomize over a relatively lower range of prices. On the other hand, when the green premium is significantly high (such that it exceeds the relative production cost advantage of the dirty technology), the clean type has a strong incentive to adopt an ecolabel rather than signal through prices. Adopting an ecolabel enables the clean type to undercut a dirty rival, without being punished by the beliefs of buyers who may associate lower prices with lower production cost i.e., dirty technology. Armed with the ecolabel, a clean firm is able to exercise its

[9] The stochastic nature of the final outcome of any R&D investment in the carbon capture and sequestration (CCS) technology qualifies it to be an example of the process innovation described in this paper.

full competitive advantage and in fact, to capture the entire market when the rival is dirty; the clean type randomizes over prices to balance its stochastic monopoly power when the rival is dirty, with the incentive to engage in price undercutting when the rival is clean. The dirty types engage in the marginal cost pricing.

Interestingly, if no ecolabels are available, the market outcome for this case of high green premium is one where firms signal their types only through prices, with the clean firms charging high prices but ceding the market to the dirty rivals that charge relatively low prices. In fact, signaling through prices requires the dirty types to earn sufficient rent so as to not imitate the prices of the clean types. Consequently, the clean type has to charge a very high price to deter any imitation. This, in turn, allows a competing dirty firm to steal the entire market at relatively higher prices when the rival is of the clean type. The reason, this can be sustained as an equilibrium outcome, is primarily because the buyers cannot directly observe the types and thus, the beliefs (of the buyers) punish the clean firms that try to undercut and gain market share from the dirty rivals. As a result, the market power of firms tends to be high which creates multiple distortions; for example, the buyers buy from the dirty firms even when the clean product is available and the clean type creates higher social surplus. Buyers, however, learn about the true type of the firms from prices even though no ecolabels are available. Thus, the provision of a credible ecolabel (at small cost) is not necessary to enable the buyers to make more informed purchase decisions. The present analysis indicates that the main reason why provision of a credible ecolabel is desirable, is because it *removes the market power and the distortions associated with the price signaling outcome*; it shifts the market share from the dirty to the clean firms that can now use the ecolabel to exercise their competitive advantage. Consequently, the environmental outcome is improved and so is the social welfare.

Finally, I analyze a firm's long run incentive to invest in the development of a clean technology where investment is publicly observable but the outcome (success or failure) is only known to the firm. Relative to a benchmark situation where no ecolabels are available and firms signal through prices, the ability to credibly disclose through an ecolabel improves a firm's *ex ante* unilateral incentive to invest (i.e., when its rival does not invest). Surprisingly, the presence of an ecolabel does not necessarily increase a firm's reciprocal incentive to invest (i.e., when its rival also invests) relative to the price signaling benchmark. This is because, in the price signaling outcome, the incomplete information (created by uncertainty about the realized technology of a firm that invests) can eventually increase market power to deter imitation of the clean type's price by the dirty type;

this can create additional incentive to invest that is not present when types are disclosed directly through the ecolabel.

The remainder of the paper is organized as follows. The next section describes the basic model. In Section 3, I examine how the green premium affects firms' decisions to adopt an ecolabel to disclose their environmental performances as well as other market outcomes. Section 4 presents an augmented version of the basic model, discusses whether competing firms have strategic incentive to invest, and studies their equilibrium investment behaviors. In the last two aforementioned sections, I also compare the equilibrium market outcomes with and without the availability of any credible ecolabel. The last section concludes.

2 The basic model

I consider a market where the production process of two firms that compete in prices may cause an environmental damage. The production technology of each firm can be of two potential types *dirty* (D) and *clean* (C). The products of the firms are not differentiated in any dimension other than the environmental impacts of their respective production technologies. Each firm produces at a constant unit cost. The unit production costs of a clean type and a dirty type are defined by m_C and m_D respectively.

There is a unit mass of risk-neutral consumers in the market. Consumers have unit demand i.e., each consumer buys at most one unit of the good. All consumers are environmentally conscious[10] in the sense that they are willing to pay a premium, $\Delta > 0$, for a unit of the clean type's product; I will refer this as the *green premium* in the rest of the paper. The *green premium* that the consumers are willing to pay for the product produced by the cleaner technology acts as the *measure of environmental consciousness* of consumers. The consumers have identical valuation V for a unit of the dirty product and $(V + \Delta)$ for a unit of a clean product. I assume that $V > m_C$ and $V > m_D$.

I assume that the clean type is produced at a higher unit cost i.e.,

$$0 < m_D < m_C.$$

This happens to be the standard assumption in the existing literature. Note that there are two

[10] An alternative and more general structure is where a fraction of consumers are environmentally conscious and a strictly positive fraction does not care i.e., this group of people are not willing to pay the green premium for the product produced by cleaner technology. If I introduce this heterogeneity among the consumers then the qualitative nature of the equilibria in this paper do not change; rather it just makes the characterization of the equilibrium technically messy and complicated.

scenarios. The first scenario arises when the green premium that the environmentally conscious consumers are willing to pay is lower than the cost difference between the clean and the dirty production technologies

$$\Delta \leq m_C - m_D. \qquad \text{(Low-green premium)}$$

I refer this as the *low-green premium* scenario. In this case, $V + \Delta - m_C \leq V - m_D$ which implies that the surplus generated by the dirty type is higher than that of the clean type. Thus, when the firms compete in prices under full information, a dirty type can capture the entire market reducing the market share of the clean type to zero; in other words, the dirty type has a competitive advantage over the clean type in case of the low-green premium. Alternatively, the *high-green premium* scenario is the one when the green premium exceeds the cost difference

$$\Delta \geq m_C - m_D. \qquad \text{(High-green premium)}$$

In this case, the clean type generates higher surplus ($V + \Delta - m_C \geq V - m_D$) and has competitive advantage over the dirty type as it takes away the entire market of environmentally conscious consumers when firms compete strategically in terms of prices with the complete knowledge of each others' environmental performances.

Formally, I have a three-stage game. First, nature independently draws the type (environmental performance) of the production technology of each firm from a distribution that assigns probabilities $\mu \in (0, 1)$ and $(1 - \mu)$ to C and D respectively. The realization of the type of the production technology of a firm remains private knowledge to the firm and unknown to the rival firm as well as to the consumer. In the next stage, firms (having observed their own types) simultaneously decide whether to adopt a credible ecolabel and also choose prices to disclose the environmental performance to consumers. For the sake of simplicity, I assume that there is only one credible binary eco-label offered by a third-party certifier and the cost of adopting such an ecolabel is strictly positive but sufficiently small. Finally, consumers, after observing the firms' decisions to adopt the ecolabel and their prices, decide to buy. The pay-off of each firm is its *expected profit* whereas the pay-off of each consumer is her *expected net surplus.*

I investigate the effects of the availability of the ecolabel and the green premium on certain market variables. Though most of these variables are typical market outcomes, to avoid any confusion, I define them explicitly in the context of this specific model. The *market power* of a firm is defined by the firm's ability to charge a price higher than its own marginal cost and is measured

by the mark-up i.e., difference between the equilibrium price and the respective marginal cost. Note that I do not explicitly define an environmental damage function, but I consider the probability that the dirty type sells in the equilibrium as a good proxy for the *expected environmental damage* created by the industry.

One of the main objectives of this paper is to compare firms' market behavior under three different information disclosure mechanisms that the firms can use to reveal their own environmental performance to rivals and to the consumers. In the rest of the paper, I will refer *ex ante* expected profit of a firm when firms can disclose their environmental performances (1) *with the ecolabel as well as by signaling via prices*, (2) *by signaling via prices without any credible ecolabel* (discussed in Appendix B), and (3) *under mandatory disclosure laws* (see Appendix C) with superscripts E, S, and M respectively.

3 Market outcomes with a credible ecolabel

In this section, I critically examine a firm's incentive to disclose its environmental performance to consumers via the credible ecolabel as well as through market prices. I also investigate how the green premium affects short run market outcomes such as market power, expected profit, and expected environmental damage in the presence of the ecolabel. Finally, I compare these market outcomes with that of the ones, when there is no ecolabel and firms signal their own environmental performances via their prices.

I find that a clean type does not always find it profitable to adopt the ecolabel to credibly disclose its environmental performance to consumers. In particular, this is true when the green premium (that environmentally conscious consumers are willing to pay) is lower than the cost differential between the clean and dirty type. However, when the green premium is sufficiently high (such that it generates comparatively higher surplus for the clean type), the clean type adopts the ecolabel in the equilibrium apart from signaling its environmental impact through its prices. Thus, one can conclude that the level of the green premium (which measures the environmental consciousness) determines a firm's incentive to adopt the ecolabel. Further, I show that the availability of the ecolabel yields less distortionary equilibrium market outcomes compared to a disclosure regime without any ecolabel aka signaling via price. To be more specific, under high-green premium, unlike in the case signaling, the clean type does not have to charge an exceptionally higher price to prevent the dirty type from imitating; rather adoption of the ecolabel in the equilibrium helps the

clean type to charge a less distortionary price. The clean type always sells to the entire market when it discloses its type by adopting the ecolabel. This, in turn, implies that the expected environmental damage is lower with the ecolabel compared to that of signaling via price.

First, I solve the *two-sided incomplete information* simultaneous move game played by the firms in the second stage, where the firms with private knowledge about their own environmental performance decide whether to adopt the ecolabel and compete in prices. The solution concept used is that of perfect Bayesian Nash equilibrium.

Proposition 1 *Under significantly low-green premium* $\left(\Delta \leq \frac{(m_C - m_D)}{2}\right)$ [11], *the clean type charges a deterministic price which is equal to its marginal cost whereas the dirty type randomizes over an interval viz.,*

$$p_C = m_C \text{ and } p_D \in [\mu (m_C - \Delta) + (1 - \mu) m_D, m_C - \Delta],$$

in the unique perfect Bayesian Nash equilibrium. The clean type sells only when the rival is of clean type too, otherwise all environmentally conscious consumers buy from the dirty type. No firm adopts the credible ecolabel.

Proof. Under the low-green premium, the dirty type generates higher surplus and thus, has competitive advantage over the clean type. The dirty type can undercut and capture the entire market in the state when the rival firm is of clean type but faces a fear of being undercut when the rival is of dirty type as well. To strike a balance between these two opposing forces, the dirty type randomizes over a price interval $\left[\underline{p}_D, \overline{p}_D\right]$. The upper bound of the interval ($\overline{p}_D$) is a price at which an environmentally conscious consumer is indifferent between buying from the dirty type and from the clean type i.e., $p_C = \overline{p}_D + \Delta$. The dirty type charges a price less than $\overline{p}_D$ almost surely, since otherwise the rival dirty type can undercut to earn higher profit. This, in turn, implies that a clean type can only sell in the state when the rival is of clean type. Therefore, in the equilibrium, the clean type ends up charging a price as low as its marginal cost (m_C). The existence of this equilibrium is guaranteed, since the upper bound of the price support of the dirty type ($\overline{p}_D = m_C - \Delta$) is greater than its marginal cost ($m_D \leq m_C - \Delta$). The equilibrium expected profit of the dirty type for charging any price $p \in [\underline{p}_D, \overline{p}_D]$ is given by

$$\pi_D = [\mu + (1 - \mu)(1 - F_D(p))] (p - m_D). \tag{1}$$

[11] It can be proved that for any green premium $\frac{(m_C - m_D)}{2} \leq \Delta \leq (m_C - m_D)$, no clean type adopts an ecolabel.

In a state where its rival is a clean type, a dirty type can charge $\overline{p}_D$, sells to all consumers, and earns a strictly positive profit equal to

$$(\overline{p}_D - m_D)\,\mu = (m_C - \Delta - m_D)\,\mu \tag{2}$$

which is identical to the equilibrium expected profit of the dirty type π_D. The lower bound of the support $\left(\underline{p}_D\right)$ is the lowest price that the dirty type wants to undercut, given that it is going to capture entire market irrespective of the type of its rival; it earns strictly positive expected profit which is equal to π_D. This implies $\underline{p}_D - m_D = \pi_D = (m_C - \Delta - m_D)\,\mu$. Therefore, the lower bound of the support is

$$\underline{p}_D = \mu\,[m_C - \Delta] + (1-\mu)\,m_D. \tag{3}$$

At every price $p \in \left[\underline{p}_D, \overline{p}_D\right]$, the dirty type can sell to all consumers as long as the rival of dirty type does not undercut, and its expected profit at p is equal to $[\mu + (1-\mu)(1 - F_D(p))]\,(p - m_D)$; this is equal to π_D for every price $p \in \left[\underline{p}_D, \overline{p}_D\right]$ i.e.,

$$\pi_D = [\mu + (1-\mu)(1 - F_D(p))]\,(p - m_D) = (m_C - \Delta - m_D)\,\mu \tag{4}$$

which implies that

$$F_D(p) = 1 - \frac{\mu}{(1-\mu)}\left(\frac{m_C - \Delta - m_D}{p - m_D} - 1\right) \tag{5}$$

where $F_D(p)$ is continuous on $\left[\underline{p}_D, \overline{p}_D\right], F_D\left(\underline{p}_D\right) = 0$, and $F_D(\overline{p}_D) = 1$. In the Bayesian Nash equilibrium, a clean type can sell only in the state where its rival is clean too, and they equally divide the market among themselves as consumers are indifferent between firms. The incentive compatibility constraint of the dirty type i.e.,

$$\frac{\mu}{2}(m_C - m_D) \leq (m_C - \Delta - m_D)\,\mu$$

implies that $\Delta \leq \frac{(m_C - m_D)}{2}$, and that of the clean type is trivially satisfied. The expected equilibrium profit of the clean type is zero irrespective of its rival's type. This implies that no firm has an incentive to adopt the ecolabel in the equilibrium.

The incomplete information Bayesian equilibrium described above can be supported by the following out-of-equilibrium beliefs of consumers: if a firm charges any (off equilibrium) price other than the effective marginal cost of the clean type (viz., $p > m_C$ or $p < m_C$) then consumers believe that

the firm is of clean or dirty type respectively with probability one. Given these out-of-equilibrium beliefs, no firm has an incentive to unilaterally deviate to any off equilibrium price. It can be argued that these out-of-equilibrium beliefs satisfy the D1 refinement; the set of quantities for which it is profitable for a clean type to deviate to any price $p > m_C$ is larger than that of the dirty type, and since a clean type will never deviate to any price below its own effective marginal cost D1 refinement is trivially satisfied in this case.

Next, I check whether any firm has any incentive to deviate from the above mentioned equilibrium strategies. There is no reason for the clean type to adopt the ecolabel at marginal cost pricing as the price does signal the environmental performance of the firm. A more pertinent question is whether the clean type wants to deviate to a higher price with the help of the credible ecolabel, and the answer is no. Because in this case, all environmentally conscious consumers attain higher surplus if they buy from the dirty type that can easily undercut the clean type. Note that the dirty type does not want to charge a price above its upper bound either, as it will lose all its market to the clean type.

■

The above proposition depicts two major sources of *distortion*. One stems from the fact that all environmentally conscious consumers, though they are willing to pay more for the product produced by the cleaner technology, often end up buying from the dirty type except when both firms are of clean type in the equilibrium. Even though the equilibrium prices reveal the actual environmental impact of the production process of the dirty firms, the inability of a clean type to offer a competitive price drives the cleaner firms away from the market. This, in turn, leads to additional distortion in the equilibrium market outcomes. In particular, even if the clean type has an option to voluntarily adopt the credible ecolabel to disclose its own environmental performance to the consumer, individual clean firm chooses not to do so in the equilibrium. However, both distortions vanish from the equilibrium outcomes when the green premium is high enough to generate competitive advantage for the clean type.

Proposition 2 *Under high-green premium*$(\Delta \geq m_C - m_D)$, *the clean type randomizes over an interval whereas the dirty type charges its own marginal cost viz.,*

$$p_C \in [\mu m_C + (1-\mu)(m_D + \Delta), m_D + \Delta] \text{ and } p_D = m_D$$

in the unique perfect Bayesian Nash equilibrium. The clean type caters to the entire market, adopts

the credible ecolabel, and the dirty type sells only when the rival is of dirty type as well.

Proof. Under the high-green premium, the clean type generates higher surplus and thus, has competitive advantage over the dirty type. The clean type can capture the entire market in the state when the rival firm is of dirty type but faces a fear of potential aggressive price competition when the rival is of clean type as well. Consequently, the clean type randomizes over a price interval $\left[\underline{p}_C, \overline{p}_C\right]$. The upper bound of the interval ($\overline{p}_C$) is a price at which an environmentally conscious consumer is indifferent between buying from the clean type and from the dirty type i.e., $p_D = \overline{p}_C - \Delta$. The clean type charges a price less than $\overline{p}_C$ almost surely, since otherwise the rival clean type can undercut to earn higher profit. This, in turn, implies that a dirty type can sell only in the state when the rival is of dirty type as well. Therefore, in the equilibrium, the dirty type ends up charging a price as low as its marginal cost (m_D). The existence of this equilibrium is guaranteed, as the upper bound of the price support of the clean type ($\overline{p}_C = m_D + \Delta$) is greater than its marginal cost ($m_C \leq m_D + \Delta$). The equilibrium expected profit of the clean type for charging any price $p \in [\underline{p}_C, \overline{p}_C]$ is given by

$$\pi_C = \left[(1-\mu) + \mu(1 - F_C(p))\right](p - m_C). \tag{6}$$

In a state where its rival is a dirty type, a clean type can charge $\overline{p}_C$, sell to all consumers, and earns a strictly positive profit equal to

$$(\overline{p}_C - m_C)(1-\mu) = (m_D + \Delta - m_C)(1-\mu) \tag{7}$$

which is identical to the equilibrium expected profit of the dirty type π_C. The lower bound of the support $\left(\underline{p}_C\right)$ is the lowest price that the clean type wants to undercut, given that it is going to capture entire market irrespective of the type of its rival; it earns strictly positive expected profit which is equal to π_C. This implies $\underline{p}_C - m_C = \pi_C = (m_D + \Delta - m_C)(1-\mu)$. Therefore, the lower bound of the support is

$$\underline{p}_C = \mu m_C + (1-\mu)(m_D + \Delta). \tag{8}$$

At every price $p \in \left[\underline{p}_C, \overline{p}_C\right]$, the clean type can sell to all consumers as long as the rival of clean type does not undercut, and its expected profit at p is equal to $\left[(1-\mu) + \mu(1 - F_C(p))\right](p - m_C)$;

this is equal to π_C for every price $p \in \left[\underline{p}_C, \overline{p}_C\right]$ i.e.,

$$\pi_C = \left[(1-\mu) + \mu(1 - F_C(p))\right](p - m_C) = (m_D + \Delta - m_C)(1-\mu) \tag{9}$$

which implies that

$$F_C(p) = \frac{1}{\mu}\left[1 - (1-\mu)\left(\frac{m_D + \Delta - m_C}{p - m_C}\right)\right] \tag{10}$$

where $F_C(p)$ is continuous on $\left[\underline{p}_C, \overline{p}_C\right], F_C\left(\underline{p}_C\right) = 0$, and $F_C(\overline{p}_C) = 1$. In the perfect Bayesian Nash equilibrium, a dirty type can sell only in the state where its rival is dirty too, and they equally divide the market among themselves as consumers are indifferent between firms. The expected equilibrium profit of the dirty type is zero irrespective of its rival's type. Since the clean type earns strictly positive expected profit, it adopts the credible ecolabel in the equilibrium.

The incomplete information Bayesian equilibrium described above can be supported by the following out-of-equilibrium beliefs of consumers: if a firm does not adopt an ecolabel (off equilibrium) then consumers believe that the firm is of dirty type with probability one. Given these out-of-equilibrium beliefs, no firm has an incentive to unilaterally deviate to any off equilibrium ecolabel adoption decision and price. It can be argued that these out-of-equilibrium beliefs satisfy the D1 refinement; the set of quantities for which it is profitable for a clean type to deviate to any price $p > m_C$ *without any ecolabel* is lower than that of the dirty type, and since a clean type will never deviate to any price below its own effective marginal cost D1 refinement is trivially satisfied in this case.

Does the clean type have any incentive to deviate from the above mentioned equilibrium strategy? Observe that it is trivial to show that the clean type does not want to deviate to any out-of-equilibrium price *with the ecolabel*. I consider two other possible deviations; the clean type does not adopt an ecolabel and either charges the same price or a different price. In case the clean type does not adopt the ecolabel then the price charged by the clean type should act as a signal for the environmental performance. The out-of-equilibrium belief says that if consumers observe a price $p \in [\mu m_C + (1-\mu)(m_D + \Delta), m_D + \Delta]$ *without any ecolabel* they believe that the firm is of dirty type. Therefore, a clean type has no incentive to not adopt the ecolabel at this range of prices. The clean type does not have any incentive to charge a price lower or higher than its equilibrium lower or upper bound respectively as it will be regraded as a dirty type. ■

From the above proposition, one can conclude that less distortionary equilibrium outcomes can be obtained under the high-green premium. In the equilibrium, the clean type not only adopts the

ecolabel to disclose its environmental performance to the consumers but also manages to capture the entire market and earns strictly positive expected profit. Incomplete information about the type of the rival softens the price competition and creates positive expected profit for the clean type even when the rival is of the same type. The *ex ante* expected profit of a firm is

$$\pi^E = \begin{cases} \mu(1-\mu)\left(m_C - \Delta - m_D\right) & \text{if } \Delta \leq \frac{m_C - m_D}{2} \\ \mu(1-\mu)\left(m_D + \Delta - m_C\right) & \text{if } \Delta \geq m_C - m_D \end{cases} . \tag{11}$$

The following corollary illustrates the effect of the environmental consciousness of the consumers on the market power and expected profit of a firm. Rise in the level of environmental consciousness among consumers is measured by the increase in the green premium that the environmentally conscious consumers are willing to pay for the cleaner product.

Corollary 1 *Consider the high-green premium* $(\Delta \geq m_C - m_D)$ *scenario when the ecolabel is available. An increase in the environmental consciousness* (Δ) *among consumers increases the market power and the expected profit of a firm and the expected environmental damage is lower compared to that under low-green premium*$\left(\Delta \leq \frac{m_C - m_D}{2}\right)$.

Next, I compare the (above mentioned) market outcomes with and without the availability of the ecolabel. For the detailed market analyses under the information disclosure regimes without ecolabel viz., signaling via price please see Appendix B. The next Proposition summarizes the interesting features of the comparative analyses across these two disclosure regimes.

Proposition 3 *(i) Under high-green premium*$(\Delta \geq m_C - m_D)$, *the availability of the ecolabel yields less distortionary equilibrium outcomes compared to signaling via prices. The clean type always sells under the high-green premium equilibrium with the ecolabel whereas it may not sell when firms can only signal through price.*
(ii) Under high-green premium$(\Delta \geq m_C - m_D)$, *the expected environmental damage is lower with the ecolabel compared to that of the signaling via price.*

The underlying reason behind less distortionary and environmentally superior market outcomes with the ecolabel compared to that of signaling via price is as follows. In the signaling equilibrium, the dirty type needs to have market power and earn strictly positive rent, so that it does not have the incentive to imitate the clean type's price. This incentive to imitate increases with increase in the green premium that environmentally conscious consumers are willing to pay; this implies that

to prevent the dirty type, the clean type has to increase its price as well. Thus, when environmental consciousness among all consumers is pretty high, without the availability of the ecolabel the clean type cannot sell when there is a dirty type in the market. To be precise, the probability that the dirty type sells in the signaling equilibrium is higher than that of with the ecolabel (i.e., $(1-\mu^2) > (1-\mu)^2$). Note that the expected profit of a firm is higher in case of signaling compared to the regime with the ecolabel, also because of the positive rent earned by the dirty type. However, the market power of the dirty type under signaling always decreases with increase in the green-premium.

4 Investment in clean technology

In this section, I consider an augmented version of the basic model (discussed in Section 2). In particular, I assume that firms are initially endowed with a dirty production technology, which means that each firm incurs a unit cost of m_D. In the first stage, firms simultaneously decide whether or not to invest in the development of the clean technology. This is a long run decision that cannot be modified in the short run. The actions chosen by each firm at this stage i.e., whether or not it has invested is observed by both firms and consumers. If it does not invest, a firm remains dirty with probability one, and this is known to all. If it invests then the realized production technology is clean with probability $\mu \in (0,1)$[12] and dirty with probability $1-\mu$, but the realized production technology is pure private information - unknown to the rival firm as well as to consumers. The realizations of production technology after investments are independent across firms. If a firm attains the clean technology as a result of investment then the firm incurs an effective marginal cost of m_C. In the next stage, firms simultaneously decide whether to adopt the ecolabel and also choose prices to disclose the environmental performance to consumers. Finally, consumers decide to buy.

Note that there are three possible information structures in the second stage ecolabel-adoption and pricing game, following any profile of investment (long run) decision made in the first stage. In the first case, both firms decide not to invest, both remain dirty for sure, and the pricing game degenerates to a standard (1) *full information* symmetric Bertrand price competition game. For any value of green premium, both firms charge a common price equal to the effective marginal cost of production of the dirty type (m_D), and both earn zero profit. A more interesting case arises

[12] It can be alternatively interpreted as the probability that the newly developed technology eliminates accidents that can damage the environment or prevents currently unknown externalities on the environment in the future.

under the second situation viz., when only one firm invests. Here the pricing game is a (2) *one-sided incomplete information* game; the firm that invests is clean with probability μ and remains dirty with probability $(1-\mu)$, while the firm that does not invest stays dirty for sure. I discuss this particular case in detail later in Appendix A. Lastly, I consider the scenario where both firms invest in the first stage. In this case, the final outcomes of the investment undertaken by both firms are private information i.e., firms do not know each others' type when they strategically compete in terms of prices and decide whether to adopt ecolabel. I primarily focus on this (3) *two-sided incomplete information* framework in this paper and have already discussed the relevant market outcomes with ecolabel in the previous section[13].

The *ex ante expected profit* of a firm is

$$\mu\pi_C + (1-\mu)\pi_D \qquad \text{(Expected profit)}$$

where π_C is the clean type's expected profit and π_D is the dirty type's expected profit. I denote the *ex ante* expected profit of an investing firm by π_{II} and π_{INI} if the rival invests and does not invest respectively, whereas the *ex ante* expected profits of a non-investing firm given that the rival invests and does not invest are denoted by π_{NII} and π_{NINI} respectively. In this paper, the *strategic incentive* of a firm to invest in cleaner technology is defined by the difference between the *ex ante* expected profit of the firm if it invests and the expected profit when it does not invest. The strategic incentive to invest differs between situations where the rival firm does not invest and the rival invests. In particular, the *unilateral incentive* (UI) to invest in cleaner technology is defined as the difference between *ex ante* expected profit of an investing firm when the rival does not invest and the expected profit of a firm when both firms do not invest

$$UI = \pi_{INI} - \pi_{NINI} \qquad \text{(Unilateral incentive to invest)}$$

whereas the *reciprocal incentive* (RI) to invest is the *ex ante* expected profit of an investing firm when both firms invest minus the *ex ante* expected profit of a non-investing firm when the rival invests

$$RI = \pi_{II} - \pi_{NII}. \qquad \text{(Reciprocal incentive to invest)}$$

If $UI \geq 0$ then a firm has an incentive to invest in cleaner technology even if the rival does not

[13] Later in the paper in Appendix B, I discuss the case where in the absence of any ecolabel and mandatory disclosure laws prices act as the only credible information disclosure mechanism.

invest; moreover if $RI \geq 0$ then a firm has reciprocal incentive to invest. In equilibrium, at least one firm invests if the unilateral incentive to invest is at least as high as the fixed cost $(UI \geq F)$, and both firms invest when the reciprocal incentive to invest exceeds the fixed cost of investment $(RI \geq F)$.

In this section, I discuss the effect of the green premium (i.e., environmental consciousness of consumers) on a firm's strategic (unilateral as well as reciprocal) incentive to invest and their equilibrium investment behavior. I also compare the strategic incentives and equilibrium investment behavior of firms with and without the option of credibly disclosing environmental performance via the ecolabel. I find that even though under low-green premium a firm does not have any reciprocal incentive to invest, when the green premium is high enough (to generate relatively higher surplus for the clean type compared to the dirty) the reciprocal incentive becomes strictly positive. However, presence of the ecolabel does not necessarily improve a firm's reciprocal incentive to invest compared to the disclosure regime without any ecolabel i.e., signaling via price. Further, only one firm may invest in the equilibrium with the ecolabel under low-green premium whereas both firms invest (provided that the cost of investment is below certain threshold) when the green premium is high. Interestingly, when the green premium is low, no firm invests under mandatory disclosure even if there is no cost of investment.

The unilateral incentive to invest (when the ecolabel is available) is given by

$$UI^E = \pi^E_{INI} - \pi^E_{NINI} = \begin{cases} \mu(1-\mu)\left(m_C - \Delta - m_D\right) & \text{if } \Delta \leq \frac{m_C - m_D}{2} \\ \mu\left(m_D + \Delta - m_C\right) & \text{if } \Delta \geq m_C - m_D \end{cases}, \tag{12}$$

and it is strictly positive for any level of green premium. The reciprocal incentive to invest is given by

$$RI^E = \pi^E_{II} - \pi^E_{NII} = \begin{cases} -\mu^2\left(m_C - \Delta - m_D\right) & \text{if } \Delta \leq \frac{m_C - m_D}{2} \\ \mu(1-\mu)\left(m_D + \Delta - m_C\right) & \text{if } \Delta \geq m_C - m_D \end{cases}. \tag{13}$$

Note that under the low-green premium, a firm does not have any reciprocal incentive to invest, whereas it is strictly positive when the green premium is high. The intuition is as follows. Recall that under the low-green premium, the clean type has zero market power, whereas the non-investing dirty type enjoys market power with probability one. Thus, the non-investing dirty type earns higher strictly positive expected profit compared to the investing firm. This implies that a firm has negative reciprocal incentive to invest under the low-green premium. However, the positive externality (negative of reciprocal incentive) enjoyed by the non-investing dirty type decreases as

the green premium increases. Finally, it disappears when the green premium is high enough to generate competitive advantage for the clean type. In this case, the clean type has market power whereas the dirty type does not. This, in turn, generates higher expected profit for the investing firm compared to the non-investing one and creates strictly positive reciprocal incentive to invest.

Finally, I investigate the equilibrium investment behavior of firms when there is no mandatory disclosure laws and firms voluntarily decide whether to disclose their environmental performance via the ecolabel. In particular, I consider the first-stage investment game where firms simultaneously decide whether to invest in cleaner technology where the outcome is uncertain and find the Nash equilibrium by comparing the ex ante expected profit of the investing as well as the non-investing firms.

Proposition 4 *Consider the case where the credible ecolabel is available.*
(i) When the green premium is low $\left(\Delta \leq \frac{m_C - m_D}{2}\right)$, *only one firm invests in the cleaner technology in the equilibrium iff the fixed cost of investment is less than equal to* $F_2 = \mu(1-\mu)(m_C - \Delta - m_D)$.
(ii) When the green premium is high $(\Delta \geq m_C - m_D)$, *both firms invest in the cleaner technology in the equilibrium iff the fixed cost of investment is less than equal to* $F_1 = \mu(1-\mu)(m_D + \Delta - m_C)$.

Proof.

	Invests	Does not Invest
Invests	$\pi^E_{II} - F, \pi^E_{II} - F$	$\pi^E_{INI} - F, \pi^E_{NII}$
Does not Invest	$\pi^E_{NII}, \pi^E_{INI} - F$	$\pi^E_{NINI}, \pi^E_{NINI}$

π^E_{II} and π^E_{INI} are the *ex ante* expected profits of an investing firm when the rival invests and does not invest respectively, and π^E_{NII} and π^E_{NINI} are the *ex ante* expected profits of a non-investing firm when the rival invests and does not invest respectively in the presence of the ecolabel. Observe that (i) $\pi^E_{II} = \mu(1-\mu)(m_C - \Delta - m_D), \pi^E_{NII} = \mu(m_C - \Delta - m_D), \pi^E_{INI} = \mu(1-\mu)(m_C - \Delta - m_D)$, and $\pi^E_{NINI} = 0$ when the green premium is low. In the unique Nash equilibrium, only one firm invests if $\pi^E_{INI} = F_2 \geq F$ where F is the fixed cost of investment.
(ii) If the green premium is high then $\pi^E_{II} = \mu(1-\mu)(m_D + \Delta - m_C), \pi^E_{NII} = 0, \pi^E_{INI} = \mu(m_D + \Delta - m_C)$, and $\pi^E_{NINI} = 0$. Both firms invest in the equilibrium iff $F \leq F_1 = \pi^E_{II}$ where F is the fixed cost of investment. ■

It might be useful to explicitly summarize the sub game perfect Nash equilibrium with the presence of the ecolabel. If the green premium is low then only one firm invests (provided the fixed cost is below F_2), no firm adopts the ecolabel, and the dirty type is the only one that caters

to the environmentally conscious consumers (even though they are willing to pay a higher price for the product of a firm with cleaner technology). Whereas under the high premium, both firms invest (given the fixed cost is below F_1), the clean type adopts the credible ecolabel, charges a price higher than its own marginal cost, and always sells in the market. In other words, higher green premium creates competitive advantage for the clean type. This, in turn, generates incentive for the firms to invest in the cleaner technology. In the absence of any mandatory disclosure laws, incomplete information about the final investment outcome softens price competition and enables clean type to earn strictly positive expected profit. Therefore, the clean type decides to disclose its environmental performance to consumers by adopting the credible ecolabel.

To the best of my knowledge, this is the first attempt to compare the equilibrium investment behavior of strategically competing firms and other market outcomes with and without an ecolabel. The interesting findings are summarized in the following Proposition.

Proposition 5 *(i) In the absence of any ecolabel, high-green premium fails to create any unilateral incentive for firms to invest in the cleaner technology, whereas the incentive becomes strictly positive when a clean firm can voluntarily disclose its environmental performance via the credible ecolabel. (ii) Presence of the ecolabel does not increase a firms' reciprocal incentive to invest. In other words, the reciprocal incentive to invest is higher without any ecolabel compared to that of with an ecolabel. (iii) When the green premium is low, no firm invests in the equilibrium under mandatory disclosure whereas at least one firm invests in the presence of an ecolabel or price as a disclosure device.*

The strategic incentive to invest under low-green premium($\Delta \leq m_C - m_D$) arises only because the dirty type can take the advantage of incomplete information about its rival's type; therefore, under mandatory disclosure there is no unilateral incentive to invest $\left(\text{i.e., } UI^M = 0\right)$, whereas it is strictly positive in the presence of the ecolabel and when firms signal via prices without an ecolabel $\left(UI^E = UI^S > 0\right)$. When the premium increases significantly, (such that the clean type generates higher surplus ($\Delta \geq m_C - m_D$)) then a firm has a strictly positive incentive to invest under mandatory disclosure as well as with the ecolabel $\left(UI^M = UI^E > 0\right)$. This is mainly because, under mandatory disclosure, the clean type can earn strictly positive profit when it has a competitive advantage over the dirty type. However, under the high premium, the unilateral incentive becomes zero without any ecolabel $\left(UI^S = 0\right)$, as the clean type cannot sell to any consumer when the equilibrium price acts as a signal for the environmental performance of the firms. Note that part (ii) also implies that there is a range of fixed costs for which both firms invest under signaling but

do not invest when the clean type has the option of adopting the ecolabel.

5 Conclusion

In this paper, I critically analyze a firm's strategic incentive to adopt a credible ecolabel in order to disclose its environmental performance to the (environmentally conscious) consumers who are willing to pay a green premium (i.e., a higher price for the good produced with a technology the creates lower environmental damage). In particular, I consider a market where two *ex ante* symmetric firms strategically compete in prices. I find that the cleaner firms do not necessarily adopt the credible ecolabel, even when the cost of adoption is negligible. However, unlike the existing literature on ecolabels, the cleaner firms signal their environmental performance through their prices when they do not adopt any ecolabel. If the green premium is high (enough to exceed the cost differential between the clean and the dirty firm), the cleaner type does adopt the ecolabel in the equilibrium. In this case, the adoption of the ecolabel removes market and welfare distortions generated by the equilibrium outcomes when firms signal only via prices. To be specific, I show that in the presence of the ecolabel, the cleaner firms sell more often and thus, reduce the expected environmental damage compared to that of the equilibria under price signaling. I also examine the effects of the ecolabel on the firms' *ex ante* strategic incentives to invest in the cleaner technology and on the resulting investment equilibria.

Appendix A: Only one firm invests (with the availability of the ecolabel)

I consider the case where in the first stage only one firm invests to become cleaner which leads to a one-sided incomplete information structure in the following pricing game. If the investing firm becomes clean, it tries to convince the consumers that it is of clean type by adopting a credible ecolabel whenever it is profitable to do so. I argue that there exists a unique Bayesian equilibrium of the one-sided incomplete information pricing game where the investing firm charges a higher price when it is of clean type than when it is dirty. The clean type has more incentive to charge higher price because of its relatively higher marginal cost.

Lemma 1 *If only one firm invests and the green premium is low* $(\Delta \leq m_C - m_D)$*, then the clean type charges its own marginal cost* (m_C) *and sells zero whereas the dirty type randomizes over a*

price interval $[\mu(m_C - \Delta) + (1-\mu)m_D, m_C - \Delta]$ *and all consumers buy from the dirty type, in the unique Bayesian Nash equilibrium. No firm adopts any ecolabel.*

Proof. Under the low-green premium, the dirty type generates higher surplus and has a competitive advantage over the clean type. The non-investing dirty type can undercut the investing rival in case it is of the clean type but has a fear of being undercut by the rival dirty type. Thus, the non-investing dirty type randomizes over a price interval $\left[\underline{p}_D, \overline{p}_D\right]$, where the upper bound is set at the price where an environmentally conscious consumer is indifferent between buying from the dirty type and the clean type i.e., $p_C = \overline{p}_D + \Delta$. The dirty type charges a price less than $\overline{p}_D$ almost surely, since otherwise the rival dirty type can undercut to earn higher profit. This, in turn, implies that a clean type sells zero for sure and earns zero profit in the equilibrium. Therefore, in the equilibrium the clean type ends up charging a price as low as its marginal cost (m_C). The existence of this equilibrium is guaranteed, because the upper bound of the price support of the dirty type ($\overline{p}_D = m_C - \Delta$) is greater than its marginal cost ($m_D \leq m_C - \Delta$). Since at price $\overline{p}_D$, the dirty type of the investing firm undercuts the non-investing firm with probability one, at price $\overline{p}_D$ the non-investing firm sells only in the state where the rival investing firm is of the clean type; the equilibrium expected profit of the non-investing firm is given by

$$\pi^E_{NII} = \mu[\overline{p}_D - m_D] = \mu(m_C - \Delta - m_D) \tag{14}$$

for charging any price $p \in [\underline{p}_D, \overline{p}_D]$, and the dirty type of investing firm earns the same expected profit. The lower bound of the support $\left(\underline{p}_D\right)$ is the lowest price that the dirty type wants to undercut, given that it is going to capture the entire market irrespective of the type of its rival; it earns strictly positive expected profit which is equal to π_D. This implies $\underline{p}_D - m_D = \pi_D = (m_C - \Delta - m_D)\mu$. Therefore, the lower bound of the support is

$$\underline{p}_D = \mu[p_C - \Delta] + (1-\mu)m_D. \tag{15}$$

The non-investing firm assigns a probability mass of μ to the upper bound of its price support $(\overline{p}_D)$, as it knows that the rival investing firm becomes clean with probability μ. At every price $p \in [\underline{p}_D, \overline{p}_D]$, the non-investing firm can sell to all consumers as long as it is not undercut by the dirty type of the rival investing firm, and its expected profit at p is equal to π^E_{NII} viz. $[\mu + (1-\mu)(1 - F_I(p))](p - m_D) = (\overline{p}_D - m_D)\mu$. This yields the probability distribution function

of the dirty type of the investing firm

$$F_I(p) = 1 - \frac{\mu}{1-\mu}\left[\frac{\overline{p}_D - m_D}{p - m_D} - 1\right],\ p \in [\underline{p}_D, \overline{p}_D] \tag{16}$$

where $F_I(p)$ is a continuous distribution function with no probability mass at any point, $F_I(\underline{p}_D) = 0$, and $F_I(\overline{p}_D) = 1$. Similarly, at every price $p \in [\underline{p}_D, \overline{p}_D]$ the dirty type of the investing firm can sell to all consumers as long as it is not undercut by the rival non-investing firm, and its expected profit at p is equal to π^E_{NII} viz. $(p - m_D)(1 - F_{NI}(p)) = (\overline{p}_D - m_D)\mu$; this yields the probability distribution function of the non-investing firm

$$F_{NI}(p) = 1 - \mu\frac{\overline{p}_D - m_D}{p - m_D}, p \in [\underline{p}_D, \overline{p}_D] \tag{17}$$

where $F_{NI}(\overline{p}_D) = 1 - \mu$ and $F_{NI}(\underline{p}_D) = 0$. The dirty type of the investing firm follows the same pricing strategy. There is no incentive to adopt the ecolabel for the investing firm, as the dirty type generates higher surplus and the clean type can never sell. ■

The above lemma depicts an interesting and somewhat surprising outcome where the clean type does not adopt an ecolabel in the equilibrium to disclose its environmental performance to the environmentally conscious consumers and cannot sell to any of them. The green premium, that the environmentally conscious consumers are willing to pay for the good produced by the cleaner technology, is not significantly high enough to beat the cost differential of the two types; this leads to higher surplus and creates competitive advantage for the dirty type. This, in turn, attributes to the failure of the clean type to capture any market segment. Therefore, it is not at all profitable for the clean type to adopt an ecolabel to disclose its environmental performance. However, the clean type does adopt an ecolabel when the opposite holds true, i.e., when the green premium is high enough to exceed the cost differential which generates competitive advantage for the clean type. Following lemma illustrates the pricing equilibrium under the high-green premium.

Lemma 2 *If only one firm invests and the green premium is high* $(\Delta \geq m_C - m_D)$*, then the clean type charges* $(m_D + \Delta)$*, caters to the entire market whereas the dirty type charges its own marginal cost* (m_D) *and sells only if the investing rival remains dirty. The clean type adopts ecolabel, but the dirty type does not in the equilibrium.*

The equilibrium pricing behavior of the firms under high-green premium is same as it is under the mandatory disclosure laws and somewhat desirable, compared to the outcomes under the low-

green premium, in the sense that the clean type not only adopts an ecolabel but also sells to the entire market. The clean type enjoys competitive advantage over the dirty type, because either the willingness of environmentally conscious consumers to pay for the product of the clean type is significantly higher or the marginal cost differences between the clean and the dirty type is low. Thus, the clean type can afford to drive down its own price to a price (viz., $m_D + \Delta$) at which an environmentally conscious consumer is indifferent between buying from the clean type and from the dirty type at its marginal cost (m_D), and this equilibrium price charged by the clean type is higher than its own marginal cost $(m_D + \Delta \geq m_C)$. Note that the dirty type still charges a lower price than that of the clean type. Therefore, to capture the entire market of environmentally conscious consumers, the clean type has to adopt an ecolabel in the equilibrium to credibly disclose its environmental performance. In other words, the dirty type cannot sell anything in the state where the investing rival firm is of the clean type. The best price that the non-investing dirty type can charge in the equilibrium is its own marginal cost irrespective of the rival's type. In the state where the investing firm fails to adopt the cleaner technology and thus remains dirty, it charges the same price as its non-investing rival; however, in this case they equally share the market and earn zero profit. To summarize,

$$\pi^E_{INI} = \begin{cases} \mu(1-\mu)\left(m_C - \Delta - m_D\right) & \text{if } \Delta \leq m_C - m_D \\ \mu\left(m_D + \Delta - m_C\right) & \text{if } \Delta \geq m_C - m_D \end{cases} \quad \text{and} \tag{18}$$

$$\pi^E_{NII} = \begin{cases} \mu\left(m_C - \Delta - m_D\right) & \text{if } \Delta \leq m_C - m_D \\ 0 & \text{if } \Delta \geq m_C - m_D \end{cases} . \tag{19}$$

It is indeed interesting to note that under the low-green premium, the non-investing firm enjoys a kind of positive externality $\left(\text{i.e., } \pi^E_{NII} > \pi^E_{INI}\right)$ due to its rival's decision to invest in the cleaner technology.

Appendix B: Signaling via price (without any ecolabel)

Consider a scenario, where there is neither any mandatory disclosure laws imposed on the firms nor a credible ecolabel available for the firms to reveal their respective environmental performances to the consumers. In the absence of any of the aforementioned disclosure mechanisms, the firms can signal their environmental quality via their respective prices when the consumers are aware of the marginal cost associated with both types of technology. This particular case has been

discussed extensively in Sengupta (2015). However unlike this paper, in Sengupta (2015) not only the environmental consciousness of consumers but also the expected future liability associated with the future environmental damage motivates the competing firms to strategically invest in the cleaner technology, and there is a fraction of consumers who are not willing to pay the green premium for the product of the clean firm. One of the main objectives of this paper is to compare the pricing and the investment equilibria under different environmental performance disclosure mechanisms viz., adoption of the ecolabel, signaling through price, and mandatory disclosure. To do so, in this section, first I consider the three-stage game as described in Sengupta (2015) . In the first stage, the firms simultaneously decide whether to invest in a cleaner technology where the final outcome is uncertain. The final outcome of the investment remains private knowledge. In the next stage, the firms choose prices simultaneously to signal the environmental performance to the consumers. The solution concept used in the signaling game is that of the Perfect Bayesian Equilibrium which is supported by the out-of-equilibrium beliefs[14] that satisfy Cho-Sobel (1990) D1 Criterion[15]. Finally, the consumers observe the prices charged by the firms, update their beliefs, decide whether to buy, and from which firm to buy. I briefly discuss the pricing and the investment equilibria (in the light of Sengupta (2015)). Observe that the pricing equilibria when no firms invest and only one firm invests with a low-green premium ($\Delta \leq m_C - m_D$) are qualitatively similar to the cases where the firms can voluntarily adopt a credible ecolabel.

Lemma 3 (Segupta (2015)**)** *(i) When only one firm invests and the green premium is high* ($\Delta \geq m_C - m_D$)*, the dirty type charges its marginal cost* (m_D) *and all consumers buy from the dirty type with probability one whereas the clean type charges a higher price* ($m_D + \Delta$) *and sells zero in the unique D1 separating equilibrium.*

(ii) When both firms invest, in the unique D1 separating equilibrium a clean type charges a deterministic price p_C *which is higher than any price charged by a dirty type and sells only when the rival is of the clean type too; the dirty type follows a mixed strategy with support* $\left[\underline{P}_D, \overline{P}_D\right]$ *and a continuous distribution function* $F_D(p)$*, where*

$$p_C = \begin{cases} m_C & \text{if } \Delta \leq \frac{m_C - m_D}{2} \\ m_D + 2\Delta & \text{if } \frac{m_C - m_D}{2} \leq \Delta \leq V - m_D \\ V + \Delta & \text{if } \Delta \geq \frac{m_C - m_D}{2} \text{ and } \Delta \geq V - m_D \end{cases}$$

[14] See Footnote 15 in Sengupta (2015) .
[15] See Footnote 16 in Sengupta (2015) .

$$\overline{P}_D = p_C - \Delta \text{ and } \underline{P}_D = \mu\left[p_C - \Delta\right] + (1-\mu)\, m_D.$$

If *one firm invests* the clean type earns zero expected profit ($\pi_C = 0$) for any level of green-premium whereas the dirty type earns strictly positive expected profit ($\pi_D = \mu\left(m_C - \Delta - m_D\right)$) under low-green premium$\left(\Delta \leq \frac{m_C - m_D}{2}\right)$. When *both firms invest* even though all consumers are environmentally conscious the clean type can only sell when both firms are of the clean type and can make strictly positive profit only under the high green-premium. In this case, in the first stage the equilibrium expected profits of the clean type and the dirty type are

$$\pi_C = \begin{cases} 0 & \text{if } \Delta \leq \frac{m_C - m_D}{2} \\ \frac{\mu}{2}\left(m_D + 2\Delta - m_C\right) & \text{if } \frac{m_C - m_D}{2} \leq \Delta \leq V - m_D \\ \frac{\mu}{2}\left(V + \Delta - m_C\right) & \text{if } \Delta \geq \frac{m_C - m_D}{2} \text{ and } \Delta \geq V - m_D \end{cases}$$

and

$$\pi_D = \begin{cases} \mu\left(m_C - \Delta - m_D\right) & \text{if } \Delta \leq \frac{m_C - m_D}{2} \\ \mu\Delta & \text{if } \frac{m_C - m_D}{2} \leq \Delta \leq V - m_D \\ \mu\left(V - m_D\right) & \text{if } \Delta \geq \frac{m_C - m_D}{2} \text{ and } \Delta \geq V - m_D \end{cases}$$

respectively. Note that when the green premium is reasonably high to generate comparatively higher surplus (which, in turn, generates competitive advantage) for the clean type but not high enough to beat the social surplus generated by the dirty type, the incentive for the dirty type to imitate the clean type is not too strong and thus, the clean type can afford to charge a price below its full information monopoly price $(V + \Delta)$. Interestingly, in this particular range of the green premium ($m_C - m_D \leq \Delta \leq V - m_D$), increase in the green premium increases the expected profit of the clean type as well as that of the dirty type.

The *ex ante* expected profit of an investing as well as a non-investing firm given the rival invests and does not invest are

$$\pi_{II}^S = \begin{cases} (1-\mu)\,\mu\left(m_C - \Delta - m_D\right) & \text{if } \Delta \leq \frac{m_C - m_D}{2} \\ \frac{\mu^2}{2}\left(m_D + 2\Delta - m_C\right) + (1-\mu)\,\mu\Delta & \text{if } \frac{m_C - m_D}{2} \leq \Delta \leq V - m_D \\ \frac{\mu^2}{2}\left(V + \Delta - m_C\right) + (1-\mu)\,\mu\left(V - m_D\right) & \text{if } \Delta \geq \frac{m_C - m_D}{2} \text{ and } \Delta \geq V - m_D \end{cases}, \tag{20}$$

$$\pi_{INI}^S = \begin{cases} \mu\left(1-\mu\right)\left(m_C - \Delta - m_D\right) & \text{if } \Delta \leq m_C - m_D \\ 0 & \text{if } \Delta \geq m_C - m_D \end{cases}, \tag{21}$$

$$\pi^S_{NII} = \begin{cases} \mu\left(m_C - \Delta - m_D\right) & \text{if } \Delta \leq m_C - m_D \\ 0 & \text{if } \Delta \geq m_C - m_D \end{cases}, \tag{22}$$

and $\pi^S_{NINI} = 0$. I calculate the unilateral and the reciprocal incentive to invest as follows

$$UI^S = \pi^S_{INI} - \pi^S_{NINI} = \begin{cases} \mu\left(1-\mu\right)\left(m_C - \Delta - m_D\right) & \text{if } \Delta \leq m_C - m_D \\ 0 & \text{if } \Delta \geq m_C - m_D \end{cases} \quad \text{and} \tag{23}$$

$$RI^S = \pi^S_{II} - \pi^S_{NII} = \begin{cases} 0 & \text{if } \Delta \leq \frac{m_C - m_D}{2} \\ \frac{\mu^2}{2}\left(m_D + 2\Delta - m_C\right) + \left(1-\mu\right)\mu\Delta & \text{if } \frac{m_C - m_D}{2} \leq \Delta \leq V - m_D \\ \frac{\mu^2}{2}\left(V + \Delta - m_C\right) + \left(1-\mu\right)\mu\left(V - m_D\right) & \text{if } \Delta \geq m_C - m_D \text{ and } \Delta \geq V - m_D \end{cases} \tag{24}$$

respectively. It is easy to see that a firm has strictly positive unilateral incentive under low-green premium whereas high-green premium generates strictly positive reciprocal incentive to invest. The intuition is not too different from the case where the firms can voluntarily choose an ecolabel to disclose their environmental performances. The investment equilibria are described in the next proposition.

Proposition 6 *When the firms signal their respective environmental performances via prices,*
(i) under low-green premium $\left(\Delta \leq \frac{m_C - m_D}{2}\right)$ *only one firm invests to become cleaner in the equilibrium iff the fixed cost of investment is lower than* $F_2 = \mu\left(1-\mu\right)\left(m_C - \Delta - m_D\right)$.
(ii) under high-green premium $\left(\Delta \geq m_C - m_D\right)$ *both firms invest in the cleaner technology iff the fixed cost of investment is lower than* $F_3 = \frac{\mu^2}{2}\left(m_D + 2\Delta - m_C\right) + \mu\left(1-\mu\right)\Delta$ *when* $\Delta \leq V - m_D$ *and* $F_4 = \frac{\mu^2}{2}\left(V + \Delta - m_C\right) + \mu\left(1-\mu\right)\left(V - m_D\right)$ *when* $\Delta \geq V - m_D$.

Proof.

	Invests	Does not Invest
Invests	$\pi^S_{II} - F, \pi^S_{II} - F$	$\pi^S_{INI} - F, \pi^S_{NII}$
Does not Invest	$\pi^S_{NII}, \pi^S_{INI} - F$	$\pi^S_{NINI}, \pi^S_{NINI}$

π^S_{II} and π^S_{INI} are the *ex ante* expected profits of an investing firm when the rival invests and does not invest respectively, and π^S_{NII} and π^S_{NINI} are the *ex ante* expected profits of a non-investing firm when the rival invests and does not invest respectively when the firms signal their environmental quality through prices.

Observe that (i) when the green premium is low $\pi^S_{II} = \mu\left(1-\mu\right)\left(m_C - \Delta - m_D\right), \pi^S_{NII} = \mu\left(m_C - \Delta - m_D\right), \pi^S_{INI}$

$\mu(1-\mu)(m_C-\Delta-m_D)$, and $\pi^S_{NINI}=0$. The unique Nash equilibrium is where only one firm invests iff $F \leq F_2 = \pi^S_{NII} = \mu(m_C-\Delta-m_D)$ where F is the fixed cost of investment.
(ii) Under high-green premium$(\Delta \geq m_C - m_D)$,

$$\pi^S_{II} = \begin{cases} \frac{\mu^2}{2}(m_D+2\Delta-m_C)+(1-\mu)\mu\Delta & \text{if } \frac{m_C-m_D}{2} \leq \Delta \leq V-m_D \\ \frac{\mu^2}{2}(V+\Delta-m_C)+(1-\mu)\mu(V-m_D) & \text{if } \Delta \geq \frac{m_C-m_D}{2} \text{ and } \Delta \geq V-m_D \end{cases}$$

$\pi^S_{NII}=0, \pi^S_{INI}=0$, and $\pi^S_{NINI}=0$. In the unique Nash equilibrium, both firms invest iff $F \leq F_3 = \frac{\mu^2}{2}(m_D+2\Delta-m_C)+\mu(1-\mu)\Delta$ when $\Delta \leq V-m_D$ and $F \leq F_4 = \frac{\mu^2}{2}(V+\Delta-m_C)+\mu(1-\mu)(V-m_D)$ when $\Delta \geq V-m_D$. ■

The equilibrium paths of the three-stage game discussed here look as follows. Under the low-green premium, only one firm invests in the first stage, the dirty type enjoys market power and sells to all consumers. Whereas if the green premium is high, both firms invest, the clean type sells only when both firms are of the clean type; otherwise the dirty type captures the entire market. Both the clean and the dirty type earn strictly positive rent.

Appendix C: Mandatory disclosure

Under the mandatory disclosure laws, firms are required to report their true environmental attributes to the regulatory authorities. Alternatively, the regulatory authorities can also on their own acquire information about actual environmental performance of firms and disseminate the information among public. As a result, the consumers as well as the rival firms become completely aware of the actual environmental performance of a firm. Thus, under the mandatory disclosure laws, there is no need for adoption of ecolabels by the firms. Alternatively, one can think of a mandatory multi-tier ecolabel as a proxy for the full disclosure. However, to the best of my knowledge, at present there is no mandatory (binary or multi-tier) ecolabel requirement on any industry to publicly disclose the environmental impact of the firms[16]. The standard belief suggests that since the consumers are willing to pay a green premium for the product produced by relatively cleaner technology, the firms should always have significant incentive to become cleaner when the consumers are indeed aware of the actual environmental performance of the firm. In this section, I examine the incentive of firms to invest when the investment as well as the technological outcome

[16] Following are few examples of mandatory labels that do not disclose the environmental impact of industries. The US Food and Drug Administration (FDA) requires the processed food industry to disclose the trans fat content in their products, and. EU's multi-tier energy labels reveal the energy effeciency of an eletric device.

of the investment are publicly observed.

Under the mandatory disclosure, the three-stage game described in the previous sections remains almost the same except the firms publicly disclose their realized production technologies before engaging in strategic price competition, and in the second stage the firms do not need to decide whether to adopt the ecolabel.[17] First, I describe the full information equilibrium of the second-stage pricing game. If no firm invests then both firms remain dirty for sure; as a result they involve in aggressive price competition and charge a price equal to the dirty type's marginal cost earning zero profit. The following lemma describes the pricing equilibria when at least one firm invests (either only one firm or both firms).

Lemma 4 *When at least one firm invests*
(i) if the green premium is relatively low ($\Delta \leq m_C - m_D$)*, the clean type charges its marginal cost* m_C *and the dirty type charges* $m_C - \Delta$ *if the rival if of the clean type otherwise charges its marginal cost* m_D.
(ii) if the green premium is high ($\Delta \geq m_C - m_D$)*, the clean type caters the entire market at* $m_D + \Delta$ *whereas the rival dirty type charges* m_D*. If the firms are of the same type then they charge their respective marginal costs.*

If both firms are of the same type, they aggressively compete and bring down the price to their respective marginal costs sharing the market equally. Recall that the low green premium case implies that the dirty type generates higher surplus than the clean type; thus, the dirty type has competitive advantage over the clean type. The lowest price that the clean type can charge to compete is its own marginal cost (m_C). In the pricing equilibrium with the low green premium, the dirty type caters to the entire market at a price $m_C - \Delta$ where an environmentally conscious consumer is indifferent between buying from the dirty type and the rival clean type at m_C. Thus, a firm does not have any incentive to invest in the cleaner technology when the green premium is low. However, at a reasonably higher green premium, the clean type has competitive advantage over the dirty rival and sells to all environmentally conscious consumers at a price ($m_D + \Delta \geq m_C$); this is the price at which an environmentally conscious consumer is indifferent between buying from the clean type and the dirty type at its own marginal cost (m_D). This implies that a clean type

[17] The analysis is almost similar to the muti-stage investment and signaling via price game considered in Sengupta (2015); however, in this model all consumers are environmentally conscious and there is no explicitly formulated expected liability payment for the future environmental damage. The pricing and the invest equilibria under the mandatory disclosure are not qualitatively different either.

rules the market in the presence of a dirty low cost rival when the consumers are willing to pay reasonably higher green premium. Consequently, in this case a firm has a strictly positive incentive to become cleaner i.e., invest in the cleaner technology. The following proposition illustrates the investment equilibria under the mandatory disclosure for the low as well the high green premiums.

Proposition 7 *Under the mandatory disclosure, in the equilibrium*
(i) no firm invests if the green premium is low ($\Delta \leq m_C - m_D$).
(ii) both firms invest if the green premium is high ($\Delta \geq m_C - m_D$) *and the fixed cost of investment is less than equal to* $F_1 = \mu(1-\mu)(m_D + \Delta - m_C)$.

Proof.

	Invests	Does not Invest
Invests	$\pi^M_{II} - F, \pi^M_{II} - F$	$\pi^M_{INI} - F, \pi^M_{NII}$
Does not Invest	$\pi^M_{NII}, \pi^M_{INI} - F$	$\pi^M_{NINI}, \pi^M_{NINI}$

π^M_{II} and π^M_{INI} are the *ex ante* expected profits of an investing firm when the rival invests and does not invest respectively, and π^M_{NII} and π^M_{NINI} are the *ex ante* expected profits of a non-investing firm when the rival invests and does not invest respectively under the mandatory disclosure. Observe that (i) $\pi^M_{II} = (1-\mu)\mu(m_C - \Delta - m_D), \pi^M_{INI} = 0, \pi^M_{NII} = \mu(m_C - \Delta - m_D)$, and $\pi^M_{NINI} = 0$ when the green premium is low. π^M_{II} is the profit of an investing firm when it remains dirty (with probability $(1-\mu)$) whereas the rival has become clean (with probability μ) and the dirty type charges a price $(m_C - \Delta)$ which is higher than the marginal cost of the dirty type. Similarly, I can explain other profit expressions. The unilateral and the reciprocal incentive of a firm to invest in the cleaner technology are $UI^M = \pi^M_{INI} - \pi^M_{NINI} = 0$ and $RI^M = \pi^M_{II} - \pi^M_{NII} < 0$ respectively. Thus the Nash equilibrium of this investment game is as follows; no firm invests for a strictly positive fixed cost (F). For zero fixed cost of investment there is an asymmetric invest equilibrium where only one firm invests.
Similarly, (ii) $\pi^M_{II} = (1-\mu)\mu(m_D + \Delta - m_C), \pi^M_{INI} = \mu(m_D + \Delta - m_C), \pi^M_{NII} = 0$, and $\pi^M_{NINI} = 0$ if the green premium is high. The unilateral and the reciprocal incentive of a firm to invest in the cleaner technology are $UI^M = \pi^M_{INI} - \pi^M_{NINI} > 0$ and $RI^M = \pi^M_{II} - \pi^M_{NII} > 0$ respectively. Since $\pi^M_{II} > \pi^M_{NII}$ both firms invest in the Nash equilibrium if $F \leq F_1 = \mu(1-\mu)(m_D + \Delta - m_C) = \pi^M_{II}$.
■

A firm does not have any strategic incentive to invest under the low-green premium, but both the unilateral as well as the reciprocal incentives are strictly positive when the green premium is

high enough to generate higher surplus for the clean type. The investment equilibrium under the low premium contradicts the standard belief, as no firm invests to become cleaner even when the environmentally conscious consumers are aware of the actual environmental performance of the firms. The environmentally conscious consumers need to pay a significantly higher green premium to encourage firms to invest in the cleaner technology under the mandatory disclosure. In other words, the mandatory disclosure laws are not enough to generate incentive for the firms to invest contrary to the standard beliefs.

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