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1 Introduction

Environmental policy (e.g., climate change policy) requires behavioral change for both consumers and producers. On the production side, policy makers have largely focused on designing instruments that will impose a price on emission so that firms internalize external damages into their production decisions and also to incentivize them to invest in low emission (or "green") technologies. Firms are also increasingly adopting voluntary pro-environmental manufacturing practices in the wake of a general belief that economic decision making must take a more holistic view of the world and its natural systems. Firms perceive such actions as "going green" and which are, potentially, motivated by a range of underlying interests. It is possible that firms intrinsically care about the environment or that they want to be viewed as socially responsible and/or environmentally conscious by stakeholders and consumers (Arora and Gangopadhyay 1995, Friedman 1970, Besley and Ghatak 2007, Banerjee and Shogren 2010). Identifying and understanding such a green-trend is important for designing cost-effective incentive structure as firms' social preferences motivate them to give up economic gain to protect the environment.

However, is "going green" always enough to ensure a cleaner environment even when a firm does not face any competition in the product market, lacks any incentives for strategic behavior and is intrinsically environmentally conscious? We address this question using a novel yet stylized theoretical model of a green (or environmentally conscious) monopolist. We model such a green monopolist's output choice and resulting emission level. Of course, a clear definition of green firm becomes important and we will provide one in subsequent discussion. But, in general, we argue that while a monopolist's investment in green technology and effort to internalize externality may reduce pollution per unit of output, it may not necessarily reduce aggregate pollution.

Our definition of a green firm is as follows: a green firm is one that is environmentally conscious and this consciousness manifests itself through observable and quantifiable actions.[1] Specifically, our green monopolist (i) invests in clean production technologies and

[1]The word "green" has usually been broad (and often vague) in meaning; it is generally considered

management practices; and (ii) internalizes environmental externalities while choosing output. We define a clean production technology as one that generates a smaller emission per unit of desirable output (hereafter: emission intensity) compared to another comparable technology.[2]

In examining the optimal behavior of our green monopolist, we consider fairly general demand and cost functions. We allow for the possibility that the monopolist's environmental concern may induce it to internalize environmental externalities when making production decision as well as to adopt a more environmentally benign manufacturing technology. We do not assume any a priori restriction on consumers' valuation of the monopolist's pro-environmental activities. We then explore if greater environmental concern unambiguously reduces (i) firm's output and (ii) aggregate emission damage.

Our main result shows that an increase in environmental concern will not always result in a decrease in output and, subsequently, a reduction in aggregate emission by the monopolist. In other words, a higher level of environmental concern of a firm need not necessarily be better for the environment, which is in sharp contrast to the conventional wisdom. We argue that the direction of this effect depends on the relative magnitudes of a mix of related effects. A green firm may want to reduce output because of (i) increase in marginal production costs due to adoption of green technology and (ii) internalization of externalities that reduces marginal profit. However, greener technology also implies a lower emission intensity implying a smaller contraction of output because of the second order internalization effect. This positive second order effect can be sufficiently larger

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synonymous with notions of sustainable development, environmentally benign manufacturing practices, smaller ecological footprint, etc. The emergence and subsequent popularization of it happened more through popular media than the scientific research community (Baines et al. 2012). Our definition of a green firm is general, we consider a firm to be green if it exhibits some degree of environmental concern. Broadly speaking, this is similar to, e.g., Wirl (2011), where a green player is usually someone who suffers from pain and guilt when his/her choices deviate from the social optimum.

[2]E.g., Glavič and Lukman (2007) define cleaner production as "... a systematically organized approach to production activities, which has positive effects on the environment. These activities encompass resource use minimization, improved eco-efficiency and source reduction, in order to improve the environmental protection and to reduce risks to living organisms".

than the negative effect on output if (a) greener technology reduces emission intensity to a large extent and/or (b) incremental marginal cost of production using greener technology is relatively less. If consumers value the firm's pro-environmental actions, the possibility of greater environmental consciousness increasing output is even more. This suggests that voluntary pro-environmental actions, even when guided by considerations for greater social good, need to be evaluated more judiciously.

The remainder of the paper is organized as follows. Section 2 presents all relevant functions, parameter assumptions and a complete overview of the firm's optimization problem. Section 3 presents and discusses our results and section 4 concludes.

2 Model

This section discusses all relevant functions and parametric restrictions and ends with a complete representation of the firm's problem. We consider a monopoly firm producing a single good output ($q \geq 0$). The process of production, however, generates emission (e) and the firm may or may not be concerned about environmental damage due to pollution. Let $v \in [0, 1]$ be the firm's degree of concern towards the environment, where $v = 0$ indicates no concern for the environment with a higher value of v indicating greater concern for the environment. We assume that firm's environmental concern translates to actual observable behavior in the form of (a) internalization of environmental externalities while making output/pricing decision and/or (b) investment in cleaner (more environmentally benign) production technology and management practices that reduces emission intensity.

Let $t \in [0, 1]$ measure the effectiveness of firm's production technology and management practices to reduce emission intensity. A larger value of t indicates greener technology and management practices; $t = 0$ corresponds to the base technology and management practices, which we refer to as completely brown technology, and $t = 1$ corresponds to the most environmentally friendly technology and management practices, which we refer to as completely green technology. We consider that a firm with greater concern for the environment (higher v) may adopt greener technology and management

practices (higher t).

Assumption 1. (a) If the firm's concern for the environment implies investment in greener technology and management practices, (i) $t = t(v) > 0$, $t'(v) > 0$ and $t''(v) \leq 0$ $\forall v \in (0, 1]$ and (ii) $t(1) = 1$. (b) $t = t(v) = 0$ $\forall v \in [0, 1]$ otherwise.[3]

Let $e(q, t(v))$ be the emission associated with output q and $L(e)$ be the total environmental damage due to emission. We now state the curvature properties of the emission and damage functions.

Assumption 2. (a) $e_q > 0$ and $e_{qq} \geq 0$; (b) $e_t < 0$ and $e_{tt} \geq 0$; and (c) $e_{qt} < 0$.[4]

Assumption 3. $L' > 0$ and $L'' \geq 0$

Assumption $2(a)$ states that, given the technology and management practices, total emission increases, at a non-decreasing rate, with output. Assumption $2(b)$ states that, given the level of output, total emission decreases at a non-decreasing rate with the greenness of technology and management practices. Further, in assumption $2(c)$, we assume that environmentally friendlier technology and management practices strictly diminishes the rate of change of emission over output.

It follows, from assumptions $1(a)$, $2(b)$ and $2(c)$, that, if the firm's concern towards the environment induces it to invest in greener technology and management practices, (i) total emission is decreasing and (weakly) convex in its degree of environmental concern ($e_v < 0$ and $e_{vv} \geq 0$) for any given output and (ii) higher degree of environmental concern strictly lowers the the rate of change of emission over output ($e_{qv} < 0$). Assumption 3 states that environmental damage increases at a non-decreasing rate in emission, which is in line with existing literature (see e.g., Ulph 1996, Pal and Saha 2014, 2015).

The cost function of the firm is given by the twice continuously differentiable function $C(q, t)$; the following assumption gives the relevant curvature properties.

Assumption 4. (a) $C_q > 0$, $C_{qq} \geq 0$; (b) $C_t > 0$, $C_{tt} \geq 0$; and (c) $C_{qt} \geq 0$, $C_{qqt} \geq 0$.

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[3]We will use primes to denote derivatives, e.g., $t' \equiv \frac{dt(v)}{dv}$ and $t'' \equiv \frac{d^2t(v)}{dv^2}$.

[4]We will use subscripts to denote partial derivatives, e.g., $e_q \equiv \frac{\partial e(\cdot)}{\partial q}$.

In assumption $4(a)$, given the technology, marginal cost of production is positive and non-decreasing in output. In $4(b)$, given the level of output, total cost of production increases at a non-decreasing rate in degree of greenness of technology and management practices. In addition, in $4(c)$, marginal cost of production and its rate of change with respect to output are non-decreasing in the level of greenness of technology and management practices. We define $C_{qt} > 0$ as the *marginal cost shifting effect* of greenness of technology and management practices.[5] Therefore, if the firm's concern towards the environment makes it proactive in adopting greener production technologies, i.e., $t'(v) > 0$, there is also a marginal cost shifting effect of the firm's degree of concern towards the environment $C_{qv} > 0$.

Let the firm attach a weight $w(v)$ to environmental damage in its objective function while making output/pricing decision. For simplicity, we consider a linear weight function as described in the following.[6]

Assumption 5. $w(v) = \theta \cdot v$, where $\theta \in \{0, 1\}$.

$\theta = 1$ when the firm's concern towards the environment induces it to internalize environmental externalities generated by its production while deciding the level of output/price. The extent of internalization of environmental externalities by the firm is increasing in the degree of environmental concern (v). Otherwise, $\theta = 0$ if the firm does not internalize environmental externalities regardless of whether it has any concern towards the environment or not. Firm's choice of w can be interpreted as an activity, in addition to adopting greener technologies and management practices, which forms part of it's environmentally focused activities under corporate social responsibility (CSR).[7]

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[5]There is no marginal cost shifting effect if cost function is separable, $C = f(q) + g(t)$.

[6]Qualitative result of this analysis go through, if we consider a more general weight function such that (a) $w(0) = 0$, $w(1) = 1$ and $w'(v) > 0$ $\forall v \in [0, 1]$, if the firm that has concern towards to the environment internalizes environmental externality while making output/pricing decisions, and (b) $w(v) = 0$, $\forall v \in [0, 1]$, if either the firm's concern towards the environment does not translate into internalization of environmental externality or the firm does not care about the environment at all.

[7]CSR describes those voluntary activities of a firm that specifically aim to incorporate environmental and social concerns in its decision-making process (see e.g., Croson and Treich 2014, European

Note that the extent of greenness of the firm depends on its degree of concern towards the environment (v) and whether its concern towards the environment translates to adaptation of greener technologies and management practices ($t'(v) > 0$) or internalization of environmental externalities in its decision making process ($\theta = 1$) or both. We now state a complete definition of a fully green firm.

Definition 1. A *fully green firm* is one which (a) has the highest degree of concern towards the environment ($v = 1$), (b) uses the most environmentally friendly technology and management practices ($t(1) = 1$) and (c) fully internalizes environmental externalities generated by its production ($w = 1$). On the other hand, a *completely brown firm* is one which does not have any concern towards the environment ($v = 0$).

It is often argued that consumers are willing to pay more for products that are produced using environmentally friendlier technology and/or creates less environmental damages (see e.g., Arora and Gangopadhyay 1995, Bansal and Gangopadhyay 2003, Bird et al. 2009, Cason and Gangadharan 2002). There is also empirical evidence showing consumers' increasing awareness about environmental effects of production activities. E.g., European commission (2014) finds that two-thirds of Europeans agree to pay a premium for environmentally friendly products. Further, it is often argued that environmentally focused CSR activity of a firm enhances its brand reputation and profitability (Khojastehpour and Johns 2014). In our model, we therefore allow for consumers to be conscious of the environmental impact of production. The inverse market demand function faced by the firm is given by

$$p \;=\; p(q; t(v), w(v)) \tag{1}$$

where $p \geq 0$ denotes the market price of the good. The demand function satisfies a set of properties as summarized below.

Assumption 6. $p_q < 0$ and $p_{qq} \leq 0$.

Assumption 7. If the representative consumer values firm's environmental consciousness, $p_t > 0$, $p_w > 0$, $p_{qt} \geq 0$ and $p_{qw} \geq 0$. Otherwise, if consumers do not care about the firm's environmentally focused activities, $p_t = p_w = p_{qt} = p_{qw} = 0$.

commission 2011).

Assumption 6 is a standard regulatory assumption, which implies that the demand function is downward sloping and (weakly) concave in quantity demanded. Assumption 7 allows for the possibility that market demand may be sensitive to the firm's environmentally focused activities. It implies that, if the representative consumer is conscious of the environmental impact of production, use of greener technology and management practices (higher t) and/or internalization of environmental externalities to a greater extent by the firm (higher w) increases the representative consumer's marginal willingness to pay for the good. In other words, environmentally focused activities of the firm shifts the market demand curve outward, when (at least some) consumers are green. We impose conditions $p_{qt} \geq 0$ and $p_{qw} \geq 0$ for simplicity, which implies that the firm's environmentally focused activities may also flatten the market demand curve in the presence of (at least some) green consumers.[8]

Since both $t(\cdot)$ and $w(\cdot)$ are non-decreasing functions of v (by Assumptions 1 and 5) and at least one is strictly increasing in v, by a slight abuse of notations, we can rewrite the inverse market demand function as

$$p \;=\; p(q, v). \tag{2}$$

It follows that, if (at least some) consumers are green, we have $p_v > 0$ and $p_{qv} \geq 0$, i.e., firm's environmental concern shifts (and may also flatten) the market demand curve outward. The magnitude of such outward shift of the demand curve is higher when the firm employs greener technology and management practices ($t'(v) > 0$) as well as internalizes environmental externalities ($\theta = 1$) than when it does either of the two. On

[8]An implicit assumption is that consumers can verify true values of t and w. In reality, however, consumers can often lack complete information regarding the true greenness (or environmental friendliness) of a firm or its production processes. In general, greenness can be thought of as a *credence good* where consumers are willing to pay more for an attribute of a good that is often hidden (or is prohibitively expensive to evaluate) even after consumption (see e.g., Baksi and Bose 2007, Darby and Karni 1973, Emons 1997, Kirchhoff 2000, Roe and Sheldon 2007). Examples of such goods include dolphin-safe tuna, organically produced food, low-emission electricity, free-range poultry, etc. The analysis in this paper, however, focuses on the production side of the economy and hence we make the assumption that firm's greenness is perfectly observable to the consumer, for simplicity. As explained in the following section, this assumption does not play any crucial role in this analysis.

the other hand, if each consumer is brown, firm's degree of environmental concern does not have any effect on market demand which means $p_v = p_{qv} = 0$.

The monopolist's problem is then given by

$$\underset{q}{\text{Maximize:}} \qquad \pi \;=\; [p(q,v)\cdot q - C(q,t(v))] - \theta \cdot v \cdot L\left(e\left(q,t(v)\right)\right). \tag{3}$$

We note here that, for any given level of output, an increase in firm's greenness (higher v) has four effects on total profit. First, revenue increases when, at least some, consumers are green and are willing to pay a higher price ($p_v > 0$ from equation 2). Second, cost of production increases, because, the firm adopts greener technology, which is more expensive ($c_t > 0$ and $t'(\cdot) > 0$ from assumptions $4(b)$ and $1(a)$). Third, greater internalization of externalities happens (i.e., higher weight attached to external damage in the objective function, $w' > 0$ from assumption 5) which has a direct negative effect on profit. In further discussion, we refer to this as the *pure internalization effect*. Lastly, adoption of greener technology also means lower external damages from emission because of lower emission intensity, which increases profit; we refer to this as the *second order internalization effect*.

Now, given the extent of firm's greenness (i.e., given v, $t(v)$ and θ), the first order condition for output choice is

$$\pi_q : \; [p_q(\cdot)q + p(\cdot)] - [C_q(\cdot) + \theta v L'(\cdot) e_q(\cdot)] \;=\; 0. \tag{4}$$

In equation 4, the first square-bracketed term is the marginal revenue for the monopolist and the second square-bracketed term is the marginal cost plus a part of marginal environmental damage due to production. The second order condition for a maximum of q is satisfied, since Assumptions 2– 6 imply that the objective function is concave in q, i.e., $\pi_{qq} < 0$.[9]

[9] $\pi_{qq} = 2p_q(\cdot) + p_{qq}q - C_{qq}(\cdot) - \theta v L'(\cdot) e_{qq} - \theta v L''(\cdot)\left(e_q(\cdot)\right)^2 < 0$, since we have (i) $p_{qq} \leq 0$ and $p_q < 0$ from assumption 6, (ii) $C_{qq} \geq 0$ by assumption $4(a)$, (iii) $L' > 0$ and $L'' \geq 0$ by assumption 3, (iv) $e_{qq} \geq 0$ by assumption $2(a)$ and (v) $\theta \geq 0$ by assumption 5.

3 Results and discussion

In this section, we present our results regarding the effect of degree of environmental concern on (i) monopolist's output and (ii) amount of emission damages.

To start with, note that the first order condition in equation 4 implicitly defines the monopolist's optimum choice of output,

$$q^m \;=\; q^m\left(v, t(v), \theta\right), \tag{5}$$

given its degree of concern for the environment. We can then calculate the following comparative static derivative

$$q_v \;=\; -\frac{\pi_{qv}}{\pi_{qq}} \tag{6}$$

using the implicit function theorem where $\pi_{qq} < 0$ from the second order condition. The sign of the comparative static derivative then depends on the sign of π_{qv} which is given by

$$\pi_{qv} \;=\; \left(p_v(\cdot) + p_{qv}(\cdot)q\right) + \left(-C_{qt}t'(\cdot)\right) + \left[-\theta\left(1+\eta\right)L'(\cdot)e_q(\cdot)\right], \tag{7}$$

where $\eta = \frac{\partial L'\cdot e_q}{\partial v} \cdot \frac{v}{L'\cdot e_q}$; see Appendix for derivation of equation 7. We define η as the elasticity of the "marginal effect of production on emission damages" with respect to degree of greenness. Based on our model assumptions, we can show that

$$\eta \;=\; \frac{v}{L'\cdot e_q}\left(L''e_q e_t + L'e_{qt}\right) \begin{cases} < \;0 & \text{if } t'(v) > 0 \\ = \;0 & \text{if } t'(v) = 0 \end{cases}. \tag{8}$$

That is, $\eta < 0$ if the monopolist's environmental concern translates into adoption of greener technology and management practices; otherwise, $\eta = 0$.

Looking at equation 7, an increase in the monopolist's environmental concern (v) has three effects on its marginal profit, π_q. First, the marginal revenue shifting effect, captured by the first bracketed term in equation 7, is positive (equal to zero) if at least some (none of the) consumers are green. Second, the marginal cost shifting effect, given by the second bracketed term in equation 7, is negative (equal to zero) if the monopolist's environmental concern translates (does not translate) into adoption of greener technology and management practices. Third, there is the internalization effect

given by the third term in equation 7 which consists of two further effects.[10] Even if v does not affect the monopolist's choice of technology and management practices, i.e., $t' = 0$ which means $\eta = 0$, v has the negative pure internalization effect on marginal profit given by $-\theta L' e_q < 0$. However, if v does influence the monopolist's choice of technology and management practices, i.e., $t' > 0$ which implies $\eta < 0$, then, v has the additional second order internalization effect through its effect on emission intensity.[11] This second order effect on marginal profit is positive and is captured by the $\eta\theta L' e_q > 0$ term in equation 7. Overall, the internalization effect on marginal profit,

$$-\theta\left(1+\eta\right)L'(\cdot)e_q(\cdot)\begin{cases} <0 & \text{if } -1<\eta<0 \\ >0 & \text{if } -\infty<\eta<-1 \end{cases}, \tag{9}$$

where the pure (second order) internalization effect dominates in the former (later) case. Therefore, combining equations 6 and 7, we state the following.

Lemma 1. (a) Firm's equilibrium output is decreasing in its degree of environmental concern, i.e., $\frac{dq}{dv} < 0$, if

(i) $p_v = p_{qv} = t' = 0$, $\theta > 0$ and $-1 < \eta < 0$, or

(ii) $p_v = p_{qv} = \theta = 0$ and $t' > 0$, or

(iii) $p_v = p_{qv} = 0$, $t' > 0$, $\theta > 0$ and $-1 < \eta < 0$, or

(iv) $p_v > 0$, $p_{qv} > 0$, $t' > 0$, $\theta > 0$, $-1 < \eta < 0$ and the marginal revenue shifting effect is dominated by the sum of marginal cost shifting and internalization effects, or

(v) $p_v > 0$, $p_{qv} > 0$, $t' > 0$, $\theta > 0$, $-\infty < \eta < -1$ and the sum of marginal revenue shifting and internalization effects is dominated by the marginal cost shifting effect.

(b) Firm's equilibrium output is increasing in its degree of environmental concern, i.e., $\frac{dq}{dv} > 0$, if

[10] Recall, by definition, a greener firm (i) invests more on environmentally friendly technology and management practices and (ii) internalizes external damages to a larger extent.

[11] Recall that, by definition, a more (less) environmentally friendly technology has a smaller (larger) emission intensity.

(i) $p_v = p_{qv} = 0$, $t' > 0$, $\theta > 0$, $-\infty < \eta < -1$ and the marginal cost shifting effect is dominated by the internalization effect, or

(ii) $p_v > 0$, $p_{qv} > 0$, $t' > 0$, $\theta > 0$, $-\infty < \eta < -1$ and the marginal cost shifting effect is dominated by the sum of internalization and marginal revenue shifting effects.

So, if either $t' > 0$ or $\theta > 0$, but not both, i.e., if environmental concern induces the monopolist to either employ greener technology and management practices or to internalize environmental damages at least partially, but not to do both, greater environmental concern results in lower equilibrium output, unless the marginal cost shifting effect is dominated by the sum of internalization and marginal revenue shifting effects. On the other hand, if $t' > 0$ and $\theta > 0$, i.e., if environmental concern induces it to use greener technology and management practices as well as to internalize environmental damages, then, the effect of a change in degree of environmental concern on equilibrium output depends on (i) the sign of the internalization effect which depends on the value of η and (ii) its magnitude relative to marginal revenue and marginal cost shifting effects. The following proposition summarizes the main result.

Proposition 1. Suppose that assumptions 1– 7 hold. Greater environmental concern of the monopolist results in higher equilibrium output when the monopolist internalizes environmental externalities of its production, unless (a) marginal environmental damage is inelastic with respect to the monopolist's environmental concern and (b) the cost shifting effect of the monopolist's environmental concern is sufficiently large. This is true even in the absence of demand shifting effect of the monopolist's concern towards the environment.

The intuition behind this result is as follows. Suppose that consumers are not conscious of firm's environmental consciousness so that market demand function is not sensitive to the firm's pro-environmental actions ($p_v = p_{qv} = 0$). Equation 7 is then

$$\pi_{qv} \;=\; -C_{qt}t'(\cdot) + \left[-\theta\left(1+\eta\right)L'(\cdot)e_q(\cdot)\right]. \tag{10}$$

When firm becomes more environmentally conscious, it adopts greener production technology which increases marginal cost of production and reduces marginal profit. Also,

a greener firm internalizes externalities to a larger extent which means marginal profit decreases because of the pure internalization effect. Both these effects imply that output must be reduced as environmental consciousness increases. However, greener technology also implies a lower emission intensity implying a smaller contraction of output because of the second order internalization effect. This positive second order effect can be sufficiently larger than the negative effect on output if (a) greener technology reduces emission intensity to a large extent and/or (b) incremental marginal cost of production using greener technology is relatively less and/or (c) the pure internalization effect is small. If consumers value the firm's pro-environmental actions ($p_v > 0$, $P_{qv} > 0$), the possibility of greater environmental consciousness increasing output is even more because of the positive marginal revenue shifting effect.

We next address the question that whether a greener monopolist pollutes the environment less. Note that, at equilibrium, environmental damage due to pollution by the monopolist is given by

$$L^m \;=\; L\left(e^m\left(q^m, t(v)\right)\right), \tag{11}$$

where $q^m = q^m(v, t(v), \theta)$ from equation 5. Therefore, we can write

$$\frac{dL}{dv} \;=\; L'\left[e_q\left(q_v + q_t t'\right) + e_t t'\right] \;=\; L'\left[e_q \frac{dq}{dv} + e_t t'\right] \tag{12}$$

at $q = q^m$ and where we again suppressed functional arguments for brevity. We know that $L' > 0$ by assumption 3, $e_q > 0$ by assumption 2(a), $\frac{dq}{dv} \lesseqgtr 0$ by Lemma 1, $e_t < 0$ by assumption 2(b) and $t' \geq 0$ by assumption 1. Therefore,

$$\frac{dL}{dv} > 0 \qquad \text{if} \;\; \frac{dq}{dv} > 0 \;\; \text{and} \;\; \mid e_q \frac{dq}{dv} \mid > \mid e_t t' \mid . \tag{13}$$

The following proposition summarizes the result.

Proposition 2. Suppose that assumptions 1– 7 hold. A greener monopolist does not necessarily cause lower emission damages.

4 Conclusion

Existing research in behavioral environmental economics argues that applying psychological insights to economic analyses based on rational choice theory may help sharpen

environmental policy (Carlsson and Johansson-Stenman 2012, Shogren et al. 2010). For example, if consumers and firms are guided by social preferences, they would voluntarily take privately costly actions to protect the environment. This would lead to better environmental outcomes at cheaper overall cost. We argue that such a claim, however, needs to pass through a more careful analysis (see also Croson and Treich 2014, Shogren and Taylor 2008). We investigate theoretically whether going-green necessarily means making the environment greener or not. We show that that while a monopolist's investment on green technology may reduce pollution per unit of output, it may not necessarily reduce aggregate pollution level generated by the monopolist because of the increase in output or associated negative environmental effects.

Considering fairly general demand and cost functions, the green monopolist in our model internalizes environmental externalities when making production decision and adopts a more environmentally benign manufacturing technology. We then address if greater environmental concern unambiguously reduces (i) firm's output and (ii) aggregate emission damage. A green firm may want to reduce output because of (i) increase in marginal production costs due to green-technology and (ii) internalization of externalities that reduces marginal profit. However, greener technology also implies a lower emission intensity implying a smaller contraction of output because of the second order internalization effect. This positive second order effect can be sufficiently larger than the negative effect on output if (a) greener technology reduces emission intensity to a large extent and/or (b) incremental marginal cost of production using greener technology is relatively less.

We acknowledge that our result is a theoretical possibility based on a stylized model, however, it does have important policy relevance. In future work, one could also empirically investigate if such a possibility may exist in reality. As Croson and Treich (2014) correctly points out, the empirical literature on whether environmentally conscious firms are in fact better for the environment is indeed very limited.

Appendix

Derivation of π_{qv}

Recall the first order condition from equation 4,

$$\pi_q \;=\; [p_q(q,v)q + p(q,v)] - [C_q(q,t(v)) + \theta v L'(e(q,t(v)))e_q(q,t(v))]\,. \tag{A.1}$$

Partially differentiate both sides of equation A.1 with respect to v to obtain

$$\pi_{qv} \;=\; p_{qv}q + p_v - C_{qt}t' - \theta L'e_q - \theta v L''e_t t' e_q - \theta v L' e_{qt} t' \tag{A.2}$$

where all function arguments have been suppressed for brevity. Rewrite the above as

$$\begin{aligned}\pi_{qv} \;&=\; p_{qv}q + p_v - C_{qt}t' - \theta L'e_q \left[1 + \frac{v}{L'e_q}\left(L''e_t t' e_q + L'e_{qt}t'\right)\right], \\ &=\; p_{qv}q + p_v - C_{qt}t' - \theta L'e_q \left[1 + \frac{v}{L'e_q}\frac{\partial(L'e_q)}{\partial v}\right].\end{aligned} \tag{A.3}$$

Define $\eta = \frac{\partial(L'e_q)}{\partial v}\frac{v}{L'e_q}$ as the elasticity of the marginal effect of production on emission damages with respect to degree of greenness (v) and rewrite the above as

$$\pi_{qv} \;=\; p_{qv}q + p_v - C_{qt}t' + [-\theta L'e_q\,(1+\eta)] \tag{A.4}$$

which is as shown in equation 7.

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