Incentives for Technological Development in the Presence of Environmentally Aware Consumers

Sangeeta Bansal[a*] and Shubhashis Gangopadhyay[b]

[a] *Jawaharlal Nehru University, New Delhi;*

[*] *author for correspondence;* [b] *India Development Foundation, Gurgaon, India*

Abstract:

This paper examines the effect of environmental regulation on firm's incentives to invest in developing cheaper (clean-up) technologies in a model where consumers are willing to pay for environmentally clean technologies. It focuses on two types of policies: a BAT based policy and a commitment policy. In the former policy, the standard is based on the best available technology (BAT) where the regulator re-optimizes environmental regulation in response to new technologies. However, under a commitment policy, the regulator announces a regulation and sticks to it irrespective of the firm's adopted technology. The paper finds that cleaner technologies are not adopted if the regulator announces a BAT based policy. A commitment policy not only leads to positive investment in research and development but also is welfare improving.

Keywords: Best available technology; commitment policy; environmental regulation; environmentally aware consumers; innovation; technological development; welfare.

Abbreviations: BAT—best available technology; R&D—research and development

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Address for Correspondence: C-9/5, Vasant Vihar, New Delhi 110057, INDIA. e-mail: shray@nda.vsnl.net.in

1 Introduction

Environmental policies not only need to ensure that firms have incentives to adopt existing (clean-up) technologies; they must also encourage investment in research and development (R&D) to produce cheaper and cleaner technologies. One measure of the success of environmental policy is its effect on the development and spread of clean technologies (Kneese and Schultze 1975 and Jaffe, Newell and Stavins 2002). However, as Jaffe, Newell and Stavins (page 50) point out, there is little theoretical or empirical literature that studies the effects of environmental policies on technology innovation.

Environmental policies can be broadly divided into those that use market mechanisms (like pollution taxes) and those that rely on controls (like standards). Stavins (2001) argues that market based policies can encourage firms to innovate in pollution control techniques, while control mechanisms like uniform standards can make it too costly for some firms to adhere to them. In determining the optimal policy, the standard approach is to determine the tax or a 'standard and an associated fine rate' that will induce firms to choose the socially desirable level of pollution abatement. Since socially desirable level itself depends upon available technologies, this policy, which achieves social optimum in the static case, may cause perverse incentives for innovation when considered from a dynamic perspective.

Arora and Gangopadhyay (1995), Cremer and Thisse (1999), Moraga-Gonzalez and Padron-Fumero (2002), and Bansal and Gangopadhyay (2003) have developed a class of models where consumers are willing to pay for environment-friendly products. Empirical evidence of such behavior has been reported by Konar and Cohen (1997), Khanna and Damon (1999), Teisl, Roe and Hicks (2002).[1] In this paper, we model a monopolistic firm's incentive to invest in R&D under regulatory standards in models where consumers are willing to pay for environmentally clean technologies.

The analysis of our paper takes into account two important aspects of innovation effort. The first is that the firm's innovation effort is subject to an uncertain outcome — the R&D outcome is stochastic. The second problem is that while a regulator may be able to observe the (clean-up) technology being used, it is much more difficult for her to observe the R&D effort of the firm.[2] In this scenario, a regulator can choose a standard corresponding to the available technology or one that corresponds to the improved technology. This creates a problem referred to by Freeman and Haveman (1972)—the standard set is either too weak (and hence, irrelevant) or too ambitious and impossible to meet.

As mentioned above, there are two important issues in setting standards—the level at which these are set and the penalty that firms have to pay when they do not meet these standards. Specifically, we compare two alternative policy regimes. In one, the regulator sets a standard corresponding to the best available technology and also selects a fine rate, which induces the firm to meet the standard (BAT based policy). That is, the regulator waits for a technological breakthrough before making it mandatory for the firm to follow. An example of such a policy is the Clean Water Act in the United States, in which emission standards are based on "best available technologies"(Amacher and Malik 2002). Note that this policy is not a technology mandate but a market based mixed instrument as firms are free to choose other control technologies.[3] In the other alternative, she can "anticipate" a standard, consistent with a better technology, before knowing whether the firm has succeeded in developing it. In other words, she commits to the enforcement of a standard along with a penalty for not meeting it before the firm undertakes innovation effort (commitment policy). We argue that, when the regulator knows the extent of improvement but not whether it will happen, or with what probability it will happen, the weakest and strictest standards are both sub-optimal and the optimal standard is in the interior of this range. A more important result in this paper is that it is always better for the regulator to anticipate "success" rather than wait for the technological breakthrough to happen. *Committing* to a standard, *before* the improvement actually takes place provides the right incentive for strategic firm to invest in R&D.

A new technology is modeled as a downward shift in the abatement cost function. Larger is the (downward) shift in the abatement costs, greater are the incentives to abate for both the market and the social planner. (Recall that consumers are willing to pay more for "greener" products.) However, incentives for the social planner increase faster with the fall in abatement cost parameter than incentives for an unregulated firm, since the former not only takes into account consumers' direct preference for clean goods (as does the firm), but also the indirect pollution externality. Hence, the planner wants to induce firms to clean up more than what they would otherwise do.

This gap in what the market does, and what the planner wants, increases as abatement cost falls. This could have a perverse effect on firm profitability. Consider two abatement cost functions, one uniformly lower than the other. The socially optimal standards corresponding to the two cost functions are different. We show that firm profit, when abatement costs are lower and the standard (set by the regulator) corresponds to this lower cost function, is less than that in the situation where abatement costs are higher with the correspondingly weaker standard. This happens because when the firm succeeds in developing a better technology, it is required to meet the (corresponding) stricter standard, which is costly, and thereby does not benefit as much from its investment. This creates an incentive for the firm not to generate a lower abatement cost through R&D effort. A BAT based policy hampers a firm's incentive to innovate towards lower abatement costs. On the other hand, a properly designed environmental policy reduces the uncertainty of innovation benefits and can trigger innovation. The innovation results in improving the production process, thereby off-setting the increased cost of compliance. These innovation off-sets would be greater in the presence of environmentally aware consumers, as these consumers are willing to pay a price premium for *green* products.

Our work relates to the papers examining incentives to adopt less polluting technologies in the design of environmental policy instruments. Milliman and Prince (1989) examine incentives of firms to promote technological change under different regulatory methods. They find that auctioned permits followed by emission taxes provide the highest firm incentives to promote technological change. Requate (1995) compares emission taxes and auctioned permits with regard to incentives for firms to adopt new technologies. Amacher and Malik (2002) evaluate pollution taxes in a model where a regulated firm chooses among discrete pollution abatement technologies. They find that the regulator may be better able to achieve the first best outcome when the firm moves first as compared to the case when the regulator moves first. Fischer, Parry and Pizer (2003) compare welfare effects of various policy instruments when technological innovation is endogenous.

Petrakis and Xepapadeas (1999) investigate the effect of commitment of environmental policies on environmental innovation and welfare under imperfect competition. They find that under monopoly, environmental innovation and welfare are higher if the government follows time consistent policies as compared to pre-commitment policies.

In the above papers the use of a superior technology has a known cost associated with it. These approaches are more like models of adoption than models of innovation. Our paper goes behind these models and studies "technology policy" rather than "emission policy".

Our work also relates to the literature addressing the problem of time inconsistency and commitment of environmental regulation (Yao 1988; Biglaiser, Horowitz and Quiggin 1995; Gersbach and Glazer 1999). Given a higher abatement cost function, BAT policy is "currently" optimal; however, since it takes away the incentive to innovate, it is dynamically inconsistent.

Yao (1988) analyzes the dynamic interactions between the regulator and industry in the context of standard setting regulation, given technological uncertainty and private information about innovation capacities. Biglaiser *et al.* (1995), and Gersbach and Glazer (1999) examine to what extent the problem of time-inconsistency can be resolved through issuing tradeable permits.

The rest of the paper is organized as follows. The model and its equilibrium are described in section 2. Compliance under different standards and fine rates is analyzed in section 3. Section 4 examines implications of different regulatory policies on the R&D effort of the firm and also on aggregate welfare. Section 5 concludes the paper. Appendix A contains proofs of the results, and Appendix B gives analysis of alternative model formulations.

2 The Model

A firm produces a physically homogenous product x, at zero cost. Production of this output damages the environment at the level $\bar{b} > 0$. The damage could be in the form of emission of pollutants or depletion of natural resources. Cleaning up the pollution can reduce the damage. This could be an end of the pipe cleaning process or a top of the pipe cleaner production process. For $0 \leq b \leq \bar{b}$, the cost, $c(b)$, of reducing the environmental damage to the level b from $\bar{b}$, is given by

$$c(b) = \frac{1}{4}k(\bar{b} - b)^2 \tag{1}$$

where the parameter $k > 0$ measures the level of technology.

All potential consumers, or economic agents derive utility, U, from the pollution producing good x and a composite good, *money.* Those consuming x buy one unit or none at all. The good in question has two attributes: a physical attribute and an environmental impact. The physical attribute contributes utility v to the consumer of x; the environmental damage affects the utility of all agents, those who consume x and those who do not. We further assume that all agents are environmentally conscious and, are therefore, aware of the environmental damage caused by the production of x. This awareness is translated into a *net* utility for the consumers of x, which is less than v by the extent of their feeling of "guilt" in supporting the production of an environmentally damaging good. This is reflected in the fact that the higher is b, the lower is the price that consumers are willing to pay for x (Arora and Gangopadhyay 1995; Cremer and Thisse 1999; Bansal and Gangopadhyay 2003).[4] To be more specific, if the aggregate production of x is positive, the utility function of an agent is

$$U = y + I[v(y) - \theta b - p] - \eta b \tag{2}$$

where y is the money endowment or income of the consumer, $v(y)$ is the utility derived from one unit of the physical aspect of the good for the consumer with income y, b is the environmental bad caused by the production process, implying that $\bar{b} - b$ of the bad has been cleaned up by the firm. Parameter θ is the weight attached to the disutility caused by the consumption of one unit of environmental bad, and is a measure of the degree of environmental consciousness of the consumers. The price paid by the consumer for good x, if it is bought, is given by p. Indicator function, I, takes value 1 if the good x is bought by the agent, and 0 if it is not bought by this agent. Finally η is the utility loss per unit of damage caused by the *production* of x.

Here the negative externality or the external cost borne by each household, ηb, is unrelated to the level of output. In an alternative formulation, total emissions may be written as a product of level of output and per unit emissions. Then the market outcome would not change but the socially optimal emission standard would become weaker. An analysis of the alternative formulation is given in the beginning of Appendix B.

Observe that though both η and θ have an effect of reducing net utility; η is the cost of pollution affecting both consumers and non-consumers uniformly, while θ is the perception or awareness parameter affecting only those who consume the product. While making their choices, agents take into account the direct effect of the product (θ); however, the indirect effect (η) is treated as outside their control.

In this paper it is implicitly assumed that the environmental attribute of the product, b, is perfectly observable to the consumers. Darbi and Karni (1973) refer to "credence goods" as those goods whose attributes cannot be assessed even after being consumed. Green products also have the characteristics of credence goods. If the environmental quality of the product was not observable, then consumers' willingness to pay will depend on their beliefs about the quality of the product. Often, reputable certifying agencies, or non-governmental organizations, can play the role of providing information about the environmental attribute of a product. For this paper, we will assume that such an organization exists and the consumer can obtain this information at no cost.

Total population of consumers is normalized to one. Consumers have different levels of income and the same good may yield different utility to different consumers. We assume $v'(y) < 0$, that is, v is a monotonically decreasing function of y. The marginal utility of this good falls as income increases.[5] The nature of the good is such that poor consumers derive a higher marginal utility from this good and, despite the environmental bad that the good generates, cannot do without it. Consumers with higher income levels derive a lower marginal utility from this good and are willing to buy the good only if it generates low levels of *bad.*

We assume that $v(.)$ is uniformly distributed with support $[\underline{v}, \overline{v}]$. We use the following normalization of v :

A.1: Variable v is distributed uniformly over $[0, 1]$.

Given the one to one relationship between v and y, we can characterize consumers by v rather than y. From now on, therefore, v will denote the consumer type, with a higher v implying a consumer with a lower money endowment. Henceforth, we will also suppress the argument y from v.

A.2: $\theta\overline{b} < 1$.

A.3: $k\overline{b} - 2\theta - 2\eta > 0$.

Assumption A.2 ensures a positive demand for the product, and A.3 ensures the concavity of the welfare function. Assumptions A.1-A.3 guarantee interior solutions in the market outcome and social optimum.

Market Outcome

Given the utility function, where consumers are environment conscious, the firm may decide on its own to do a positive amount of clean-up, i.e., choose a $b < \overline{b}$. The profit to the firm is

$$\pi = \alpha p - c(b); \tag{3}$$

where α denotes the aggregate demand of the product. The surplus enjoyed by a consumer of type v, from the product with emissions b at price p, is given by $v - \theta b - p$. Let $\hat{v}$ denote the marginal consumer type who is indifferent between buying and not buying the good, i.e., $\hat{v} - \theta b - p = 0$. The product is demanded by all those whose $v \geq \hat{v}$. Using A.1, the aggregate demand (α) is given by $1 - \hat{v} = 1 - \theta b - p$, thus

$$\pi = (1 - \theta b - p)p - c(b), \tag{4}$$

Given A.2, A.3, and using 1, the necessary and sufficient conditions for a unique solution are

$$\frac{\partial \pi}{\partial b} = -\theta p + \frac{k}{2}(\bar{b} - b) = 0 \tag{5}$$

$$\frac{\partial \pi}{\partial p} = 1 - 2p - \theta b = 0 \tag{6}$$

Denoting the market solutions with the superscript m, from (5) and (6) we get

$$b^m = \frac{k\bar{b} - \theta}{k - \theta^2} \tag{7}$$

$$p^m = \frac{k(1 - \theta\bar{b})}{2(k - \theta^2)} \tag{8}$$

Note that

$$\frac{\partial b^m}{\partial k} > 0; \;\; and \;\; \frac{\partial p^m}{\partial k} < 0$$

By plugging (7) and (8) in (4), firm's profit can be written as

$$\pi = \frac{p^m(1 - \theta\bar{b})}{2}$$

It follows immediately that $(\partial \pi^m / \partial k) < 0$. *Thus if a technology with a lower k becomes available, it will be used.*

In this model, there are two reasons why the market solution may not be the first best outcome. One is immediate — the inefficiency resulting from a monopolist producer. The other is the negative (environmental) externality, arising from the fact that even those who do not consume x are suffering the impact of a depleted environment. Thus, even though buyers are willing to pay for a cleaner environment, not all of the externality is internalized in the price of x.

An optimal regulation must incorporate a careful analysis of the effect of the two distortions discussed above. We now solve for the optimal provision of environmental quality.

Social Optimum

Welfare is defined as the total surplus, i.e., the sum of consumer and producer surplus generated by the production of x. Thus welfare w, is given by

$$\begin{aligned} w &= \int_{\hat{v}}^{1}(y+v-\theta b-p-\eta b)dF(v)+\int_{0}^{\hat{v}}(y-\eta b)dF(v)+\int_{\hat{v}}^{1}pdF(v)-c(b) \\ &= \int_{\hat{v}}^{1}(y+v-\theta b-\eta b)dF(v)+\int_{0}^{\hat{v}}(y-\eta b)dF(v)-c(b) \qquad (9) \end{aligned}$$

where $F(v)$ is the distribution function of v. By A.1, $dF(v) = 1.dv$. Using (1), A.1 and $\hat{v} = \theta b + p$, in (9),

$$w = y + \frac{1}{2}(1-\theta b)^2 - \frac{p^2}{2} - \frac{k}{4}(\bar{b}-b)^2 - \eta b \qquad (10)$$

Observe that the welfare expression is falling in price. We can impose a non-negativity constraint on price and then solve for the socially optimum level of emission. In an alternative formulation, the social optimum can be solved by imposing the constraint that the price is chosen by the firm to maximize profit. An analysis of the alternative formulation is provided in Appendix B. For the rest of the analysis, we refer to the social optimum that has been obtained by imposing a non-negativity constraint on the price.

A price equal to zero implies that $\hat{v} = \theta b$, and ensures that all the consumers with $v > \theta b$ are able to consume x. The social optimum, then, is obtained by choosing an optimal level of emission to maximize the welfare as given in (10). Solving for an interior solution to b, the necessary condition is

$$\frac{\partial w}{\partial b} = 0 \Rightarrow \theta^2 b - \theta + \frac{k}{2}(\bar{b} - b) - \eta = 0$$

which implies

$$b^* = \frac{k\bar{b} - 2\theta - 2\eta}{k - 2\theta^2} \qquad (11)$$

where a superscript $*$ denotes the first best value of the variable, given technology k.[6] Using A.3, $b^* > 0$. Also observe that

$$\frac{\partial b^*}{\partial k} = \frac{2\theta(1-\theta\bar{b}) + 2\eta}{(k-2\theta^2)^2} > 0 \qquad (12)$$

The socially optimal clean-up level rises as the clean-up technology becomes cheaper.

Substituting the equilibrium value of b^* from (11), and $p^* = 0$ in (10), we can obtain the value of aggregate welfare in the social optimum as

$$w^* = y + \frac{k(1-\theta\bar{b})^2}{2(k-2\theta^2)} - \frac{\eta(k\bar{b}-2\theta-\eta)}{k-2\theta^2} \tag{13}$$

This is the first best level of welfare, which the economy with technology k can achieve. *If a technology with a lower k becomes available, it improves the aggregate welfare.* This is evident from the sign of the first derivative of w^* with respect to k, which is negative.

$$\frac{\partial w^*}{\partial k} = (-)\frac{\theta^2(1-\theta\bar{b})^2 + \eta^2 + 2\eta\theta(1-\theta\bar{b})}{(k-2\theta^2)^2} < 0$$

Define the degree of inefficiency as the deviation of the market solution from the first best solution, i.e., the distance $b^m - b^*$. We then have the following results.

Proposition 1: *Let A.1-A.3 hold. (i) For any given technology, as compared to the first best, the market outcome provides a lower clean-up level and serves a smaller size of the market.*

(ii) The degree of inefficiency increases with a lowering of k.

Proof: The proof is in the appendix.

The market inefficiency can be broken down into the inefficiency caused by a monopoly producer and that from the environmental externality. Suppose that there were no external damage. Then, the people who were not buying x will not have any utility loss because others were buying. The difference in the first best and the market solution will now only be due to the market structure. The welfare expression (9) now becomes

$$w' = \int_{\hat{v}}^{1}(y+v-\theta b)dF(v) + \int_{0}^{\hat{v}} y dF(v) - c(b) \tag{14}$$

Following the same procedure as above, we can again solve for the first best b as

$$\begin{aligned} b' &= \frac{k\bar{b}-2\theta}{k-2\theta^2} \qquad (15)\\ &= b^* + \frac{2\eta}{k-2\theta^2} \qquad (16)\end{aligned}$$

The second expression on the right hand side of (16) is, therefore, the inefficiency caused by environmental externality. The effects of the two distortions on the choice of the clean-up level are in the same direction and reinforce each other.

Part (ii) of Proposition 1 is an interesting result. It shows that the incentive to deviate from the first best emission level increases as the clean-up technology improves (or the slope of the marginal cost of clean-up falls). In view of these inefficiencies in the market solution, there is a role for regulation.

3 Environmental Regulation and Compliance

We now describe the regulatory instrument that will be used. The regulatory instrument is a mixed instrument consisting of a standard and an associated fine rate. Since the regulator knows the cost parameter k, she knows the optimal level of emissions the firm should be generating. She can set a standard and make the firm pay a fine if it does not meet the standard. We are assuming perfect enforcement. That is, once the regulator decides on the standard, it is able to enforce it through an appropriate fine rate.[7] The expression for the fine rate that ensures compliance of any given standard is given below in (18). The focus of the regulation is on implementing the standard, the purpose of the fine is to ensure that the standard is met.

In general, let $\hat{b}$ be the exogenous emission standard faced by the firm, and a firm not complying with the standard is required to pay a fine f per unit of deviation from the standard. Note that the firm pays a fine only if it generates emissions more than the set standard. The profit is now a function of the regulation, as well as the optimal choices of b and p by the firm. With some abuse of notation, we continue to use π as the notation for profit, but include as arguments, f and $\hat{b}$. Thus, the profit function of the firm in the presence of such an environmental regulation is

$$\pi(., f, \hat{b}) = p(1 - \theta b - p) - f\ max[(b - \hat{b}), 0] - c(b) \tag{17}$$

Observe that as long as $b^m \leq \hat{b}$, the government regulation is irrelevant and does not affect the market solution. If, however $b^m > \hat{b}$, the regulation does have an impact on the firm.[8]

Let

$$f(\hat{b}) \equiv \frac{k\bar{b} - \theta - \hat{b}(k - \theta^2)}{2} \tag{18}$$

Plugging the value of $f(\hat{b})$ in the profit function $\pi(., f, \hat{b})$, it can be checked that given any standard $\hat{b}$, the firm complies with it for all fines $f > f(\hat{b})$. Note that for ensuring compliance to any standard $\hat{b}$, the corresponding fine depends upon the technology parameter k.

Roberts and Spence (1976) and Kwerel (1977) study models where the regulators are uncertain about firms' clean-up costs. Roberts and Spence suggest that a mixed pollution control plan involving licenses and effluent charges minimizes the expected total costs of pollution. Kwerel proposes that the mixed pollution control plan induces firms to reveal their true clean-up cost function to the regulator. Thus the problem of observing clean-up costs can be overcome by employing a mixed instrument. In this paper, assuming that the regulator can observe the clean-up technology used by the firm, we analyze a situation where she cannot observe its R&D effort.

At this stage, we introduce some notations and an assumption to take care of different technologies. For any given standard $\hat{b}$, we define $f_j(\hat{b})$ to be the same as equation (18) with k_j in place of k, $j = 0, 1$, where $k_1 < k_0$. The difference between $f(\hat{b})$ and $f_j(\hat{b})$ is that the k used in defining the former fine rate indicates the level of technology of the firm, while k_j used in defining the latter fine rate is assumed by the planner and hence could be different from the actual technology parameter of the firm. Thus while $f(\hat{b})$ ensures that the standard $\hat{b}$ would be implemented, $f_j(\hat{b})$ may not ensure the same. We will denote the maximized value of profit under this regulation, for firm type i, to be $\tilde{\pi}_i(\hat{b}, f_j(\hat{b}))$, $i = 0, 1$.

A.4: $\tilde{\pi}_0(b_1^*, f_0(b_1^*)) > 0$.

This assumption ensures that firm type 0 can make positive profit when the standard is b_1^* and the fine rate forces it to meet the standard. In a sense, this is the strictest possible regulation (lowest level of pollution allowed and the largest possible fine rate); we are assuming that firm 0 will still make positive profit and thus produce positive output. We have the following result.

Proposition 2: *Let A.1-A.4 hold and* $k_1 < k_0$*. Then* $\tilde{\pi}_0(b_0^*, f_0(b_0^*)) > \tilde{\pi}_1(b_1^*, f_1(b_1^*))$.

Proof: The proof is in the appendix.

From part (ii) of Proposition 1, we know that the gap between what the market does and what the planner wants increases as abatement cost falls. This could have a perverse effect on firm profitability. The firm profit, when the abatement costs are higher and the standard (set by the regulator) corresponds to this higher cost function, is more than the situation where abatement costs are lower with the correspondingly stricter standard. This happens because when the firm succeeds in developing a better technology, it is required to meet the (corresponding) stricter standard and thereby does not benefit from its investment. This is an important result and will be used in deriving the central results of the paper.

The aggregate welfare when the regulator implements the first best level of emission for a given k is given by

$$w(b^*) = y + \frac{3}{8}(1 - \theta b^*)^2 - c(b^*) - \eta b^* \tag{19}$$

where b^* is the first best level of pollution appropriate to the known value of k.

4 Incentives for Technological Development

In this section, we examine firm's incentives for technological development. We first study these incentives in the absence of any regulation and later examine how does environmental regulation affect them.

Development of technologies are determined through the R&D expenditures by the firm. We are assuming that though the regulator can observe the technology once it is in operation, she cannot observe the R&D effort of the firm.

Consider a three-stage game. In the first stage, the regulator announces the environment policy — a standard and a fine rate. In the beginning of the second stage, the firm decides on investment in R&D. The outcome of R&D effort is stochastic and this gets resolved at the end of this stage. With probability q, it is successful and the firm develops a new technology where k in equation (1) is equal to k_1; with probability $(1-q)$, the R&D effort is a failure, and the firm has the incumbent, or old, technology that has $k = k_0$. Of course, $k_1 < k_0$.

In the third stage, the firm decides on the clean-up technology, price and the level of clean-up. Observe that, if the R&D effort has been a failure the technology choice is trivial. For then, only one technology, k_0, is available. If, however, the R&D effort has been successful, the firm has two technologies to choose from.

The R&D technology is characterized by the probability of success. This probability is a function of the resources spent on R&D. For ease in exposition, we will work with the probability of success as the firm's choice variable in the R&D stage. If q is this probability, then $H(q)$ denotes the cost undertaken.

A.5: $H'(q) > 0,\ H'(0) = 0,\ H''(q) > 0.$

As viewed in the second stage, total cost to the firm has two components — one, investment in developing a low cost technology that is undertaken in this stage and the other, cost of cleaning the pollution that is undertaken in the next stage.

First consider the case when there is no regulation. The second stage expected profit function of the firm (Π) is the expected third stage profit less the second stage cost of R&D.

$$\Pi \equiv q\pi_1^m + (1-q)\pi_0^m - H(q) \tag{20}$$

Recall that π_1^m and π_0^m differ not only in terms of clean up cost k, but also in terms of the choice of b.

The optimal investment in R&D is given by maximizing Π with respect to q. From A.3 and A.5, the following condition is necessary and sufficient.

$$\pi_1^m - \pi_0^m - H'(q) = 0 \tag{21}$$

Following a similar procedure, we can obtain the welfare maximizing investment in R&D. Let W be the expected welfare in the first stage. Then,

$$W(q) = qw_1^* + (1-q)w_0^* - H(q) \tag{22}$$

In writing (20) and (22) we are using the result that if R&D effort is successful, profit maximization as well as welfare maximization demand that the cheaper clean-up technology be used. To define welfare in the third stage, we are assuming that any fine collected by the regulator is returned back to the producers and consumers in a non-distortionary manner.

The equilibrium investment in technology development is given by the first order condition obtained by maximizing W with respect to q, which implies

$$w_1^* - w_0^* - H'(q) = 0 \tag{23}$$

Since $w_1^* - w_0^* > 0$, it is immediate that in the overall first best, a positive investment is undertaken for developing a cheaper technology.

Proposition 3: *Let A.1-A.3, A.5 hold. (i) In the presence of environmentally aware consumers, the firm undertakes a positive amount of investment in R&D.*
(ii) However, this investment is lower than the socially optimal level.

Proof: The proof is in the appendix.

Observe that part (i) of the above result is due to the presence of environmentally aware consumers. In the absence of consumer awareness, the firm does not have any incentive to invest in developing a cheaper (cleaner) technology.

Since there is underinvestment in technological development, there is a need for regulation. The regulator cannot observe the investment in R&D, but observes the realized technology, a natural form of regulation is that she makes the regulation contingent on the realized technology. Environmental laws often emphasize phrases like *best available technology* (BAT). We'll be comparing two alternative policy regimes. In one, the regulator makes the standard and fine rate contingent on the technology that will be available in the third stage (BAT based policy). Alternatively, she announces a standard and a fine rate and commits to it regardless of the adopted technology (commitment policy).

In the three-stage game described in the beginning of this section, we can implement the BAT policy in the following manner. In the first stage of the game, the regulator announces that she will inspect clean-up technology that is being used by the firm in the final stage. By assumption, this inspection technology is perfect.[9] If the technology used is k_i, $i = 0, 1$, the standard imposed will be $\hat{b} = b_i^*$ and the fine $f_i(b_i^*)$. We know that under this regulation the firm of type i will meet the standard.

The major difference between BAT and commitment policy is that in the former policy, the standard and the fine rate are contingent on firm type, whereas in the latter policy, both the standard and the fine rate are fixed and independent of the firm type. Important thing to note is that, in a commitment policy, the standard and fine become known to the firm before it undertakes its innovation effort.

We have observed that we can define for any standard $\hat{b}$, a fine rate $f_j(\hat{b})$, which collapses to (18) for $k_j = k_i$ if firm type is i (see the paragraph before A.4).

Proposition 4: *Assume A.1-A.5. (i) If the regulator announces a policy based on BAT, the firm does not have an incentive to invest in developing a cheaper clean-up technology and, therefore, there is no investment in R&D.*
(ii) A commitment policy, $(\hat{b}, f_j(\hat{b}))$, *induces the firm to undertake a positive investment in technological development.*

Proof: (i) Recall $k_1 < k_0$. Proposition 2 tells us that the profit of firm type 1 under BAT regulation is *lower* than that of firm type 0. Thus, even if technology 1 is available, it pays the firm to implement technology 0. Knowing that it is better off using 0 in the final stage, the firm has no incentive to spend anything in developing the new technology!
(ii) Consider any given (fixed) standard and fine rate, and suppose the clean-up level achieved by the firm is b. The firm has a greater profit for this level of clean-up if it uses technology 1 instead of technology 0 (see equation (17)). Therefore, given A.5, it invests a positive

amount in developing a cheaper technology. ■.

Proposition 4 shows that in terms of investment in R&D, BAT is dominated by a commitment policy.[10] An obvious question that arises is whether BAT is dominated by a commitment policy in terms of aggregate welfare as well. Recall that amongst commitment policies, the relevant range for setting emission standards is $b_1^* \leq \hat{b} \leq b_0^*$. We, therefore, first compare BAT with a commitment policy, where standard announced is b_0^* and the associated fine is $f_0(b_0^*)$. With this fine rate, firm type 0 will comply (see equation (18)). We will argue that such a policy is better than one that is based on the technology being used. This is non-trivial because even though a BAT policy may not generate any R&D effort, it can still be a second best policy (as b_0^* could be less than both b_1^m and b_0^m).

Before we move on to welfare comparisons, some discussion of the significance of environmentally aware consumers is in order. Consider the case $\theta = 0$, or no consumer awareness. Then, it is immediate that in the absence of any regulation, firm will not undertake any abatement measures and there would be no clean-up in the third stage. Therefore, the firm will spend nothing on R&D in the first stage and $q = 0$. In this situation, a regulation would induce the firm to restrict emissions to the stipulated level, and will be better than no policy. However, once $\theta > 0$, there is an incentive for the firm, *without any regulation,* to invest in R&D (Proposition 3) and the pollution emitted is less than $\bar{b}$. What we highlight in this paper is that in the presence of environmentally aware consumers, a BAT based regulation takes away the incentive that the consumer awareness created for the firm!

In most countries governmental or non-governmental organizations play a role in informing consumers about the effects of pollution as well as the extent of such pollution generated by firms. This has the effect of raising θ, which in turn has an enabling effect on the reduction of pollution by the firm, as well as on its incentive to develop cheaper clean-up technologies. A BAT-based regulatory policy could be counter-productive in such situations where technological improvements are undertaken within the firm.

Proposition 5: *Assume A.1-A.5. (i) A commitment policy dominates BAT in terms of*

aggregate welfare.
(ii) The welfare maximizing policy standard (under a commitment policy) $\hat{\hat{b}}$ *must lie between the two first best levels of emission, i.e.,* $b_1^* < \hat{\hat{b}} < b_0^*$.

<u>Proof:</u> The proof is in appendix.

As already stated the relevant range for standards is in between b_1^* and b_0^* and for fine rates, the range is in between $f_1(\hat{b})$ and $f_0(\hat{b})$. Part (i) of Proposition 5 proves that a commitment policy consisting of setting emission standard $\hat{b} = b_0^*$, and fine rate $f_0(b_0^*)$ yields a higher welfare than BAT policy. We call this the weakest policy as b_0^* is the optimal level of pollution for the firm with the worst (highest cost) clean-up technology and $f_0(b_0^*)$ is the fine rate that ensures that this firm complies with the set standard. We already know that the strictest possible regulation is standard b_1^* and fine $f_0(b_1^*)$ (see the paragraph discussing A.4). Part (ii) examines whether either of the two extreme policies is the second best policy. It shows when the regulator knows the extent of improvement that is possible but not with what probability it will happen, the weakest and strictest standards are both sub-optimal. The optimal standard lies in the interior of this range.[11]

5 Conclusion

This paper examines effect of regulation on firm's incentives to develop cheaper clean-up technologies. Environmental policy interventions may create or hamper incentives that affect the process of technological development. The effect of policy interventions may differ in the presence of environmentally aware consumers. In the presence of such consumers, firms on their own have incentives to develop cleaner technologies and policy interventions may hamper these incentives. However, properly designed environmental policies can trigger innovation.

We find that while consumers' willingness to pay a higher price for environmentally better products induces the firm to invest in R&D effort, private benefits of technological change are inadequate. The central result of the paper is that a policy based on the best available technology, or BAT policy, takes away the incentive that consumer awareness created for the firm. Hence under such a regulatory mechanism, the firm does not invest any resources in developing a cheaper technology. It is interesting to note that the regulation that achieves a socially optimal outcome in a static analysis (based on a given clean-up technology), generates perverse incentives for developing a better technology as we extend the period of analysis.

We further find that a commitment to the stringency of environmental regulation, not only induces the firm to make a positive investment in R&D but may also be welfare improving. The commitment to the announced regulation is important because if the regulation is decided after investment in R&D, the firm cannot alter its investment decision. This uncertainty in innovation benefits may turn out to be counterproductive. Finally we examine various policies in terms of relative strictness, and find that the second best policy must lie between the two extreme policies, viz., the weakest policy and the strictest policy.

If however, there were independent agencies, which invented and patented new developments, a market for new technologies would be created and under such conditions a BAT based policy could provide a positive incentive for innovation.

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Notes

1. Hamilton (1995), Lanoie, Laplante and Roy (1998) and Dasgupta, Laplante and Mamingi(2001) study green versus dirty firms with respect to capital markets.

2. Some of the previous works dealing with asymmetry of information in the context of environment include Roberts and Spence (1976), Kwerel (1977).

3. There has been flexibility in the interpretation of BAT policy by various environmental protection agencies. Broadly BAT policy can be interpreted as either a mandatory technology, i.e., a requirement to use a certain clean technology, or setting of effluent standards that correspond to the best available technology. In this paper, we are considering the latter interpretation.

4. Alternatively, if the good in question is a cheap household fuel like firewood, its use not only damages the environment, but also is unhealthy for those who use it in their house, say, for cooking. The damaging effect on personal health reduces the net utility from its consumption.

5. An alternative way of modeling the utility function is to write it as $U = y + I[v - \theta(y)b - p] - \eta b$; here the marginal utility of the physical properties of the product is the same across all consumers, but the disutility from the pollution is different across different consumers (Bansal and Gangopadhyay, 2003). There are two reasons why this paper models it the way it does. First, the algebra is a lot simpler. Second, the way we model suggests that all consumers have the same awareness, but a poorer consumer cannot afford a superior environmental quality. This we find more attractive than the Bansal and Gangopadhyay (2003) formulation where the poor people were assumed to be less aware than the richer consumers. This implies that if everyone is made aware about the environment then the problem of pollution will be mitigated. However, we know that poorer economies are more resistant to environmentally friendly technologies even when they appreciate its importance.

Another advantage of our formulation is that θ can be interpreted as the direct damage of the product on health of the consumer (in the sense described in note 4 above), which is same across consumers. It captures the vulnerability of poor consumers to low quality products. Even if poor are equally aware of the damage caused by a particular product they cannot avoid using it. On the other hand, rich consumers buy a product only if it has low damage levels.

6. The second order condition $(\partial^2 w/\partial b^2) < 0$, or $k - 2\theta^2 > 0$, is guaranteed by A.2 and A.3.

7. Imperfect enforcement may arise when the regulator is unable to determine whether the firm has maintained the standard. One way to model this is to assume that the fine is imposed with probability $0 < h < 1$. In this case, the *expected* fine is what matters; otherwise, it does not change our analysis. It can be accommodated by inserting h in the denominator of the expression for $f(\hat{b})$.

8. Note that for $\hat{b} < b^m$, the effect of this regulation on the profit function of the firm is similar to that of an effluent tax. Consider a standard $\hat{b} = b^*$, the first best emission. We will show later that there exists a fine f^* that implements this first best. Then, the fine f^*, in conjunction with the standard b^*, equates the marginal benefit of pollution to the firm, to the marginal damage caused by it to the society. In this sense it is equivalent to a Pigouvian tax.

9. If the inspection technology is imperfect in the sense described in note 4 earlier, our qualitative results still go through when we make the appropriate changes to the fine as discussed there.

10. The fine considered in this paper is equivalent to a per unit emission tax payable on emissions above the stipulated emission standard. If instead we consider a pure emission tax levied on entire emissions, the analysis would change in the following

manner. For a given emission tax, the firm's profits are higher with a low-cost clean-up technology. It, therefore, has an incentive to develop a cheaper technology under the commitment policy. On the other hand, if the regulator does not commit to the rate of emission tax and makes it contingent on the available technology, then there will be two additional effects on incentives to innovate. With improved technology, firm's tax payments could be lower as total emissions have reduced; however, these payments may be higher because per unit emission tax rate has increased. (The socially optimal tax rate would be higher when a low-cost technology becomes available.) The overall effect on incentives to innovate would depend on the relative strengths of these two effects.

11. In our analysis, it is the standard, which has welfare effects. A fine by itself, does not affect welfare directly, as it is collected from the firm and distributed to the consumers. The fine affects welfare indirectly through affecting the choice of clean-up level by the firm.

Appendix A

Proof of Results

Proof of Proposition 1:

(i) From (7) and (11), it can be seen that

$$b^m - b^* = \frac{k\theta(1-\theta\bar{b})}{(k-\theta^2)(k-2\theta^2)} + \frac{2\eta}{k-2\theta^2} > 0$$

using A.2 and A.3. Therefore, $b^m > b^*$.

The size of the market served is given by $1 - \hat{v}$.

$$\begin{aligned} \hat{v}^m &= \theta b^m + p^m \\ &= \frac{k + \theta k\bar{b} - 2\theta^2}{2(k-\theta^2)} \end{aligned}$$

using (7) and (8). The expression for $\hat{v}^m$ can be expanded as

$$\begin{aligned} \hat{v}^m &= \frac{\theta(k\bar{b} - 2\theta - 2\eta)}{k-2\theta^2} + \frac{k^2(1-\theta\bar{b}) + 4\eta\theta(k-\theta^2)}{2(k-\theta^2)(k-2\theta^2)} \\ &> \frac{\theta(k\bar{b} - 2\theta - 2\eta)}{k-2\theta^2} = \theta b^* = \hat{v}^* \\ &\Rightarrow (1-\hat{v}^m) < (1-\hat{v}^*) \end{aligned}$$

where the second equality is from equation (11).

(ii) Recall the degree of inefficiency is $b^m - b^*$. From part (i) above

$$\frac{\partial(b^m - b^*)}{\partial k} = -\frac{\theta(1-\theta\bar{b})(k^2-\theta^4)}{(k-\theta^2)^2(k-2\theta^2)^2} - \frac{2\eta}{(k-2\theta^2)^2} < 0$$

∎

Proof of Proposition 2:

For a firm type i, $i = 0, 1$, let the set standard be its corresponding first best level, i.e., $\hat{b} = b_i^*$. Suppose the fine set is such that the firm's optimal response is to maintain the standard, i.e., fine rate is equal to $f_i(b_i^*)$. Then, suppressing the subscript, and from (4), (1) and the definition of $\tilde{\pi}(b^*, f(b^*))$, we can write

$$\tilde{\pi}(b^*, f(b^*)) = p(b^*)(1 - \theta b^* - p(b^*)) - \frac{k(\bar{b} - b^*)^2}{4}$$

where $p(b^*)$ is the price chosen by the firm to maximize its profit when it is required to meet b^* under fine rate $f(b^*)$. Since $p(b^*) = [(1 - \theta b^*)/2]$, it follows

$$\tilde{\pi}(b^*, f(b^*)) = \Big(\frac{1 - \theta b^*}{2}\Big)^2 - \frac{k(\bar{b} - b^*)^2}{4}$$

then

$$\frac{\partial \tilde{\pi}}{\partial k} = \frac{1}{2}\Big[k(\bar{b} - b^*) - \theta(1 - \theta b^*)\Big]\frac{\partial b^*}{\partial k} - \frac{1}{4}(\bar{b} - b^*)^2 \tag{24}$$

Plugging in the expression for b^*, from (11), we obtain

$$\frac{\partial b^*}{\partial k} = \frac{2\theta(1 - \theta\bar{b}) + 2\eta}{(k - 2\theta^2)^2} = \frac{\bar{b} - b^*}{k - 2\theta^2}$$

Now it can be easily checked that

$$sign\frac{\partial \tilde{\pi}}{\partial k} = sign[2\theta^3(1 - \theta\bar{b}) + k\eta] > 0$$

Given $k_1 < k_0$, the proposition follows immediately. ∎

Proof of Proposition 3:

(i) Differentiating the expected profit function equation(20) with respect to q,

$$\begin{aligned} \frac{\partial \Pi}{\partial q}|_{q=0} &= \pi_1^m - \pi_0^m - H'(0) \\ &= \pi_1^m - \pi_0^m > 0 \end{aligned}$$

using A.5. At $q = 0$, the firm's profit is increasing in q; therefore, it will invest positively in technological development.

(ii) The market solution requires

$$H'(q^m) = \pi_1^m - \pi_0^m = \frac{(k_0 - k_1)\theta^2(1 - \theta\bar{b})^2}{4(k_0 - \theta^2)(k_1 - \theta^2)}$$

The welfare maximizing solution requires

$$H'(q^*) = (w_1^* - w_0^*) = \frac{(k_0 - k_1)\theta^2(1-\theta\bar{b})^2 + \eta(k_0 - k_1)[\eta + 2\theta(1-\theta\bar{b})]}{(k_0 - 2\theta^2)(k_1 - 2\theta^2)}$$

It can be checked that $H'(q^*) > H'(q^m) \Rightarrow q^* > q^m$ using A.5. ■

Proof of Proposition 5:

(i) Recall that BAT stipulates that if the cost function is defined by k_0 then the standard will be b_0^* and the fine will be $f_0(b_0^*)$; while the standard will be b_1^* and the fine $f_1(b_1^*)$ if k_1 defines the cost function. We have already shown that under BAT, there will be no R&D (Proposition 4). Aggregate welfare under BAT, therefore, will be $w_0(b_0^*)$.

Now, consider the commitment policy $\hat{b} = b_0^*$, $f(\hat{b}) = f_0(b_0^*)$. We know from (18) that under this regulation, firm type 0 will comply and type 1 will either comply or overcomply. In other words, $b_1 = min\{b_1^m, b_0^*\}$. We will provide the proof for the case where $b_1 = b_0^*$. Similar steps would follow for the case where $b_1 = b_1^m$. The expected welfare under the above policy is given by

$$\begin{aligned} W &= qw_1(b_0^*) + (1-q)w_0(b_0^*) - H(q) \\ &= q[w_1(b_0^*) - w_0(b_0^*)] - H(q) + w_0(b_0^*) \qquad (25) \\ &= q[\tilde{\pi}_1(b_0^*, f_0(b_0^*)) - \tilde{\pi}_0(b_0^*, f_0(b_0^*))] - H(q) + w_0(b_0^*) \qquad (26) \end{aligned}$$

where q is chosen to maximize $[q\tilde{\pi}_1(b_0^*, f_0(b_0^*)) + (1-q)\tilde{\pi}_0(b_0^*, f_0(b_0^*)) - H(q)]$. Let chosen value of q be q^*. Suppressing the argument $f_0(b_0^*)$ in $\tilde{\pi}_i$, we can rewrite (26) as

$$W = q^*[\tilde{\pi}_1(b_0^*) - \tilde{\pi}_0(b_0^*)] - H(q^*) + w_0(b_0^*) \qquad (27)$$

From part (ii) of Proposition 4, we know that for a given (fixed) standard, a positive q is chosen, or

$$q^*\tilde{\pi}_1(b_0^*) + (1-q^*)\tilde{\pi}_0(b_0^*) - H(q^*) > 0$$

Hence from equation (27) $W > w_0(b_0^*)$.

(ii) First we examine that for any given standard, how does the welfare change with a change in standard. Given any regulation $\hat{b}$, $f_j(\hat{b})$, $k_1 \leq k_j \leq k_0$, type 1 firm always either complies or overcomplies, however type 0 firm may or may not comply, depending upon the factor k_j in function $f_j(\hat{b})$.

$$W = qw_1(min\{b_1^m, \hat{b}\}) + (1-q)w_0(b_0) - H(q)$$

where q is determined by

$$H'(q) = \tilde{\pi_1}(min\{b_1^m, \hat{b}\}) - \tilde{\pi_0}(b_0) + \frac{k_j(\bar{b} - \hat{b}) - \theta(1 - \theta\hat{b})}{2}(b_0 - \hat{b})$$

Observe that at $f = f_0(\hat{b})$, type 0 firm also complies with the set standard, i.e., $b_0 = \hat{b}$, thus the last term in the right hand side of above equation drops out. Then, we get

$$\begin{aligned} \frac{\partial W}{\partial \hat{b}} &= q\frac{\partial w_1(min\{b_1^m, \hat{b}\})}{\partial \hat{b}} + (1-q)\frac{\partial w_0(\hat{b})}{\partial \hat{b}} + [w_1(min\{b_1^m, \hat{b}\}) - w_0(\hat{b}) - H'(q)]\frac{\partial q}{\partial \hat{b}} \\ &= q\frac{\partial w_1(min\{b_1^m, \hat{b}\})}{\partial \hat{b}} + (1-q)\frac{\partial w_0(\hat{b})}{\partial \hat{b}} + [\tilde{\pi_1}(min\{b_1^m, \hat{b}\}) - \tilde{\pi_0}(\hat{b}) - H'(q)]\frac{\partial q}{\partial \hat{b}} \end{aligned} \tag{28}$$

At $\hat{b} = b_1^*$, the first term in (28) vanishes because, by definition, $w_1(b)$ is maximized at b_1^*. The second term is positive because, $w_0(b)$ is a (strictly) concave function (from A.2 and A.3) and $b_1^* < b_0^*$. Using envelope theorem, the third term also vanishes. Thus welfare improves when the standard is relaxed at the level b_1^*. Similarly at $\hat{b} = b_0^*$, the second term in (28) vanishes and the first term is negative, therefore, a tighter standard is welfare improving. ■

Appendix B

Alternative model formulation exercise

Case 1: *Level of pollution depends on volume of output.*

Social welfare, when pollution level and therefore, damage from environmental externality depends on the volume of output produced, is given by

$$w = y + \int_{\hat{v}}^{1} (v - \theta b) dF(v) - c(b) - \eta b(1 - \hat{v})$$

where all the consumers with a v as large as $\hat{v}$ consume the product. The proportion of consumers consuming the product is given by $1 - \hat{v}$. Using A.1

$$w = y + \frac{1}{2} - \theta b - \frac{\hat{v}^2}{2} + \theta b \hat{v} - c(b) - \eta b(1 - \hat{v})$$

Maximizing w with respect to $\hat{v}$ and b, we get the following first order conditions

$$-\hat{v} + \theta b + \eta b = 0$$

$$-\theta + \theta \hat{v} - c'(b) - \eta(1 - \hat{v}) = 0$$

yielding

$$\tilde{b} = \frac{k\bar{b} - 2(\theta + \eta)}{k - 2(\theta + \eta)^2}$$

It is easy to check that $\tilde{b} > b^*$. That is, the socially optimum standard is weaker when environmental externality depends upon volume of production than otherwise. Since the total product has been normalized to one, the volume of output is always less than one.

All the results of the paper hold if Proposition 2 holds. From equation (24), we know that

$$\frac{\partial \tilde{\pi}(\tilde{b})}{\partial k} = \frac{1}{2}\Big[k(\bar{b} - \tilde{b}) - \theta(1 - \theta\tilde{b})\Big]\frac{\partial \tilde{b}}{\partial k} - \frac{1}{4}(\bar{b} - \tilde{b})^2$$

From the expression for $\tilde{b}$, it is easy to see that

$$\frac{\partial \tilde{b}}{\partial k} = \frac{2\gamma(1 - \gamma\bar{b})}{(k - 2\gamma^2)^2}; \bar{b} - \tilde{b} = \frac{2\gamma(1 - \gamma\bar{b})}{k - 2\gamma^2}; 1 - \theta\tilde{b} = \frac{k(1 - \theta\bar{b}) - 2\gamma\eta}{k - 2\gamma^2}$$

where $\gamma \equiv \theta + \eta$. Substituting these in the expression for $[\partial\tilde{\pi}/\partial k]$,

$$\frac{\partial\tilde{\pi}(\tilde{b})}{\partial k} = \frac{\bar{b} - \tilde{b}}{2(k - 2\gamma^2)^2}\Big[k\eta(1 - (\theta + \gamma)\bar{b}) + 2\gamma\eta\theta + 2\gamma^3(1 - \gamma\bar{b})\Big]$$

A necessary and sufficient condition for $\partial\tilde{\pi}/\partial k > 0$ is the following:

$$\bar{b} < \frac{\eta k + 2\gamma\eta\theta + 2\gamma^3}{(\theta + \gamma)\eta k + 2\gamma^4}$$

Thus by imposing an upper bound on the maximum possible per unit emissions, we can ensure that our results go through for this case as well. *A simpler but sufficient condition for our results is* $1 - (\theta + \gamma)\bar{b} > 0$.

Case 2: *Social optimum under the constraint that the emission standard is implemented through the market.*

Here the price is chosen by the firm to maximize profit. In the expression for welfare as given in (10), plugging $p = [(1 - \theta b)/2]$, we obtain

$$w^c = y + \frac{1}{2}(1 - \theta b)^2 - \frac{1}{2}\left[\frac{(1 - \theta b)}{2}\right]^2 - \frac{k}{4}(\bar{b} - b)^2 - \eta b$$

where w^c denotes welfare under the constraint that price is chosen by the firm. Maximizing w^c with respect to b, we get

$$b^c = \frac{2k\bar{b} - 3\theta - 4\eta}{2k - 3\theta^2}$$

where b^c denotes social optimum in this formulation. A.1-A.3 are sufficient to guarantee an interior solution. From the expression for b^c, it is easy to see that

$$\frac{\partial b^c}{\partial k} = \frac{6\theta(1 - \theta\bar{b}) + 8\eta}{(2k - 3\theta^2)^2}; \bar{b} - b^c = \frac{3\theta(1 - \theta\bar{b}) + 4\eta}{2k - 3\theta^2}; 1 - \theta b^c = \frac{2k(1 - \theta\bar{b}) + 4\eta\theta}{2k - 3\theta^2}$$

The expression for $[\partial\tilde{\pi}/\partial k]$ remains same as given in (24). Making relevant substitutions in the expression for $[\partial\tilde{\pi}/\partial k]$,

$$\frac{\partial\tilde{\pi}(b^c)}{\partial k} = \frac{\bar{b} - b^c}{4(2k - 3\theta^2)^2}\Big\{2k[2\eta - \theta(1 - \theta\bar{b})] + 3\theta^3(1 - \theta\bar{b}) + 4\eta(k - \theta^2)\Big\} > 0$$

for $\eta > \theta$. Since we are interested in examining the problem of environmental externality, it is reasonable to assume that the objective cost of pollution (η) is greater than the perception cost of pollution, which the consumers internalize.

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