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Using effluent charges in promoting investment in water pollution control technology: a model of coordination failure among firms

Abstract

Untreated wastewater, being directly discharged into rivers, is a very harmful environmental hazard that needs to be tackled urgently in many countries. In order to safeguard the river ecosystem and reduce water pollution, it is important to have an effluent charge policy that promotes the investment of wastewater treatment technology by domestic firms. This paper considers the strategic interaction between the government and the domestic firms regarding the investment in the wastewater treatment technology and the design of optimal effluent charge policy that should be implemented. In this model, the higher is the proportion of non-investing firms, the higher would be the probability of having to incur an effluent charge and the higher would be that charge. On the one hand, the government needs to impose a sufficiently strict policy to ensure that firms have strong incentive to invest. On the other hand, it cannot be too strict that it drives out firms which cannot afford to invest in such expensive technology. The paper analyses the factors that affect the probability of investment in this technology. It also explains the difficulty of imposing a strict environment policy in countries that have too many small firms which cannot afford to invest, unless subsidised.

Keywords: water pollution, effluent tax, coordination failure, global games.
JEL Classifications: D8, O3, Q25, Q53.

Introduction

Rivers and lakes have served for so long, the needs of communities, as well as agricultural, aquaculture and industrial sectors in both developed and developing countries. Yet, the densely populated communities and different types of businesses, which have scattered along the rivers, are major point pollution sources. Massive amount of wastewater have been discharged directly into the rivers. The question that arises is as follows: provided that several countries have increasingly embraced environmental laws and regulations – though to varying extent – why do they continue to experience relatively poor environmental performance, especially when it comes to water quality?

With the presence of current environmental regulations, factories and industrial parks in different countries are required by law to meet the industrial effluent standard by treating wastewater. Nevertheless, it is important to note that the industrial effluent standards in a number of developing countries mostly specify the allowable concentration of contaminants contained in the sewage or wastewater. By failing to take into account the total amount of contaminant loading in the river ecosystem, this gives rise to a possibility that the total amount of contaminants released through discharged sewage exceeds the carrying capacity of the river ecosystem.

Given that the deterioration in the water quality poses a serious problem for the economy, what steps should be taken by the government to address the problem? Typically, there are two principle approaches to address the negative external effects, in which water pollution is one of them: Pigouvian taxes and introduction of property rights (Chichilnisky and Heal, 1995). Applying this idea to look at this issue, there are two approaches to address the problem of water pollution. First, the government can levy the effluent charge on the firms that discharge wastewater containing contaminants which exceed the announced effluent standard (Klayklung et al., 2010). This type of policy has been used in countries like Thailand, though there has been a proposal to introduce environmental taxes in Thailand, which aim at dealing with water and air pollution. The common approach used in the United States is inspired by Coase's insights, i.e., given that the problem of negative externality arise from an absence of property rights; hence, establishment of property rights through permits and quotas is necessary. The key point underlying this approach is as follows: before firms are allowed to discharge wastewater containing contaminants into the river, they must own the right to do so and such water discharge rights are conveyed by the purchase of tradable quotas (Chichilnisky and Heal, 1995). These two approaches to correct and control for pollution are indeed formally equivalent in some important ways, though not in all ways. A tradeable quota system requires polluting firms to purchase a permit or right before discharging effluent. Since this raises the private cost of pollution, in this respect, it appears to the polluter like a tax on pollution.

One strand of related literature studies the relationship between firms' incentive in undertaking R&D, which will lead to the development of new environmental-friendly products and processes and the environmental policy of the government. Ulph (1997) provides an extensive survey of literature in this

direction. Katsoulacos et al. (1999) find that tougher environmental policy does not necessarily increase R&D undertaken by firms due to two conflicting effects caused by a tougher environmental policy: a direct effect of encouraging more environmental R&D by firms and an indirect effect of raising firms' costs of production, causing firms to reduce their incentive to undertake R&D. Petrakis and Poyago-Theotoky (1997) examine the design of technology policy to influence the investment in R&D by firms in the situation, whereby the government is constrained in the exercise of environmental policy. Though not considering the issue of investment in R&D, the paper by Klayklung et al. (2010) determines the appropriate effluent tax scheme, which is designed to help prohibit the amount of pollution discharges from exceeding the carrying capacity of the river ecosystem. In this paper, we combine these two strands of literature by studying the design of effluent charge, which, on the one hand, aims to encourage investment in new technology by domestic firms, and on the other hand, ensures that the water pollution does not exceed the limit.

We argue that, despite the presence of environmental regulation and industrial effluent standards, it is the responsibility of the government to design policy on effluent charge that provide incentive to the domestic firms to invest in the wastewater treatment technology, which helps to reduce the amount of contaminants, contained in the effluent that is released into the river ecosystem. We consider an economy which comprises of both small and large firms. We study the strategic interaction between the government and the domestic firms with regards to the investment in the wastewater treatment technology and study the design of optimal effluent charge policy to be implemented by the government.

In the framework adopted in this paper, the government's objective is to design the effluent charge policy which gives domestic firms incentive to invest in the wastewater treatment technology, while ensuring that the aggregate amount of water pollution loading does not exceed the limit, a level above which there would be an irreversible damage on the river ecosystem. If the amount of aggregate pollution exceeds such limit, the government would determine which firms would be charged and how much effluent charge they face. In this model, we assume that, if a firm invests in the wastewater treatment technology, it will not face any effluent charge even though the total level of pollution exceeds the limit. The purpose of this assumption is to encourage the domestic firms, to invest in the abatement technology. The firms, which do not invest in the technology, would have to share the costs from effluent charge if the total amount of pollution exceeds the limit.

We analyse this problem in the context of a coordination game between the domestic firms in the model with asymmetric information, in which each firm receives a signal about the cost it will incur, if the total level of pollution exceeds the allowable limit. At the time the firm has to choose whether or not to invest in the wastewater treatment technology, the cost that will be charged is unknown. It is a function of the number of firms which do not invest in the abatement technology. The higher is the proportion of non-investing firms, the higher would be the probability of having to incur the effluent charge and the higher would be the cost of not investing. Thus, so long as a sufficient number of firms cooperate by investing in the wastewater treatment technology, all firms can get away with no additional cost levied on them.

By using the global games framework, we then work out the equilibrium threshold: large firms will choose not to invest in the wastewater treatment technology if they received a signal below this threshold, and will invest in the technology if they received a signal above this threshold. Our results show that the probability of investment in the wastewater treatment technology by the large firms increases with the proportion of small firms and the amount of pollution discharged by firms, while the probability of investment decreases with the cost of investment, the efficiency of the technology and the level of water pollution that the government will allow. Our analysis also points out that the more efficient is the wastewater treatment technology in reducing pollution, the higher should be the effluent charge. Moreover, if the cost of excess pollution can be transferred to the large firms, the higher would be the probability that the large firms would invest in the wastewater treatment technology.

Last but not least, in this paper, we explain that in the situation, whereby the proportion of large firms is high, the government can be stricter and ensure that large firms would invest in the wastewater treatment technology. However, when there are many small firms whose survival is important for the economy, it would be difficult to expect a very strict environmental policy.

The remainder of the paper is structured as follows. Section 1 presents the model, outlining the key assumptions and deriving the equilibrium threshold. Section 2 is devoted to discuss the results from the comparative statics analysis, discussing different factors that could affect the equilibrium threshold.

Then, we study the design of optimal effluent charge in Section 3, while the last Section concludes.

1. The model

1.1. The environment. The model has two periods: t_1 and t_2. This paper is devoted to study the strategic interaction between the government agency, which is concerned about the water quality, and domestic firms, which are uniformly distributed on a continuum of mass one. There are two types of domestic firms: small and large, where $j \in \{S, L\}$ denotes the firm's type. The proportion of small and large firms is σ and $1 - \sigma$, respectively.

The production of output y_j, results in emission of pollution e_j, contained in the effluent as the by-product. To control the aggregate amount of contaminant contained in the wastewater so that it does not exceed the carrying capacity of the river ecosystem, the government agency can impose a maximum limit on the aggregate amount of effluent at t_2, given by $P > 0$ (the amount of allowable pollution contained in the effluent without causing unacceptable deterioration in the river ecosystem). The domestic firm can choose to control the amount of contaminant contained in the wastewater discharged from its point source by investing in the wastewater treatment system, a type of abatement technology. The domestic firms' investment decision takes place at the beginning of t_1. By investing in the wastewater treatment technology, firm j's discharge of pollution is reduced to λe_j, where $0 < \lambda < 1$ and λ is referred to as the residual pollution. The cost of investment in wastewater treatment technology is given by I.

Let μ_S and μ_L denote the profit for the small and large firms, respectively. We assume that $\mu_S < \mu_L$ and $\mu_S < I$. Thus, there would be no investment in wastewater treatment technology by the small firms since they cannot afford such expensive investment. It follows that aggregate amount of pollution contained in the effluent discharged by the small firms is always σe_S.

To encourage the investment in wastewater treatment technology by domestic firms and ensure that the aggregate amount of pollution discharged into the river does not exceed the limit, the government can apply the effluent charge scheme (Thompson, 1998; Glachant, 2002; Klayklung et al., 2010). Let $\tau \in [\underline{\tau}, \overline{\tau}]$ denote the level of per unit charge for effluent in excess of the maximum limit imposed by the government P. We suppose that domestic firms receive a noisy signal on τ. Based on the observed signal, each domestic firm has to decide whether or not to invest in the wastewater treatment technology. The higher is the value of τ, the tougher would the firm perceive the penalty and the more risky would be its decision not to invest in the abatement technology.

At t_2, if the aggregate amount of pollution loading of effluent is below the limit P set by the government, the payoffs for the firm, which invested in the abatement technology and the firm, which does not invest in the technology, are given by $\mu_j - I$ and μ_j, respectively. However, if the aggregate amount of discharged pollution exceeds P, the government imposes the effluent charge on the firms that did not invest in the wastewater treatment technology. The government agency is assumed to have information on the amount of pollution contained in the waste effluent, discharged from each contributing point sources (after taking into account the seasonal variation in water quality) by, for examples, monitoring the biochemical oxygen demand (BOD) values and dissolved oxygen, as well as the knowledge on the presence of wastewater treatment technology in the firm[1]. We suppose that large firms, which invested in the wastewater treatment technology, are exempted from this effluent charge, despite the presence of residual pollution λe_j.

1.1.1. Calculation of effluent charge. The liability from effluent charge borne by the domestic firm is calculated as follows. The amount of excess pollution over an above the limit P, is multiplied by the per unit effluent charge, τ. This amount is borne by firms which failed to invest in the wastewater treatment technology. This suggests that the amount, which each of these firms needs to pay, does not only depend on the amount of pollution it discharged but also on the amount of pollution discharged by all other firms. The larger is the number of firms which do not invest in the wastewater treatment technology, the more likely that the level of aggregate pollution exceeds the limit, the more likely that the government needs to levy the effluent charge and the larger will be the effluent charge. We suppose that large and small firms do not face the same effluent charge. In particular, the amount of effluent charge levied on the large firms

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[1] This information could be available from the monitoring and inspections by the government agency to make sure that each factory and industrial park meet the industrial effluent standards.

is l times larger than that is levied on the small firms, where $l > 1$.

At t_2, the government observes the realised proportion of firms which had invested in the wastewater treatment technology and evaluates the amount of effluent charge to be levied on the non-investing firms. Subsequently, firms decide whether or not to shut down production and leave the market. We suppose that firms will choose to shut down their operation and leave the market if they make a net negative return.

1.2. Determination of equilibrium effluent charge threshold τ^*. We study the coordination game between the large firms investing in the wastewater treatment technology. To establish the equilibrium of this coordination game, we follow the global game framework of Goldstein and Pauzner (2005). We derive the unique equilibrium threshold τ^*, above which the large firms choose to invest in the wastewater treatment technology and below which the large firms do not invest in the abatement technology[1].

1.2.1. Signalling structure and threshold strategy. Conditional on the value of τ that would be realised at t_2, each firm i receives at t_1, a privately observed signal, τ_i, which is drawn uniformly from the interval $[\tau - \varepsilon, \tau + \varepsilon]$. The signals are independently and identically distributed (i.i.d.) across firms with very small level of noise, $\varepsilon \to 0$.

The threshold strategy for each large firm i would be: (1) to invest in the wastewater treatment technology if $\tau_i > \tau_i^*$; and (2) not to invest in the wastewater treatment technology if $\tau_i < \tau_i^*$. The symmetric threshold strategy would imply that $\tau_i^* = \tau^*$ for every large firm i.

One of the conditions for the existence of a unique equilibrium, is that an upper dominant and a lower dominant region must exist. The existence of the upper dominant region ensures that when a large firm receives a signal, indicating a very high penalty, it will choose to invest in the technology regardless of what the other large firms choose to do. The existence of the lower dominant region ensures that when a large firm receive a signal indicating extremely low penalty, it would definitely choose not to invest in the wastewater treatment technology.

A very small probability of an existence in these two dominant regions is sufficient (nevertheless, is required) for us to derive a unique equilibrium (see Carlsson and van Damme (1993) for the proof of this theory). If a large firm receives a signal close to a dominant region, there is a probability that there would be some large firms which have received signals within that dominant region and, therefore, have a dominant strategy. This will ensure that such large firms also follow that strategy. This process can be iterated so that we, eventually, arrive at the unique threshold point, where the large firm will be indifferent between investing and not investing in the wastewater treatment technology.

1.2.2. Derivation of equilibrium threshold τ^*. In what follows, we derive the unique equilibrium threshold τ^*. The proportion of large firms that do not invest in the wastewater treatment technology is denoted by $\omega(\tau, \tau^*)$. For the moment, let large firms choose not to invest in the wastewater treatment technology if they receive a signal less than $\hat{\tau}$. The signal obtained by a large firm i is given by τ_i. It follows that the large firm i's posterior distribution of the chosen τ, which we refer to as $z \, (= \tau/\tau_i)$, is uniform over $[\tau_i - \varepsilon, \tau_i + \varepsilon]$ and is given by:

$$f(z) = \begin{cases} \dfrac{1}{2\varepsilon} \text{ if } z \in [\tau_i - \varepsilon, \tau_i + \varepsilon] \\[2mm] 0 \text{ if } z \notin [\tau_i - \varepsilon, \tau_i + \varepsilon] \end{cases}. \qquad (1)$$

This is true for all, except those points, very close to the ends of the interval.

For each point $z \in [\tau_i - \varepsilon, \tau_i + \varepsilon]$, the large firm will believe that all other large firms would have received independently and uniformly distributed signals $[z - \varepsilon, z + \varepsilon]$ and, hence, the proportion of large firms whom it believes would not invest in the wastewater treatment technology, (i.e., those which received a signal less than $\hat{\tau}$), is a distribution $\widetilde{\omega}(z) \in [0,1]$ which is given by:

$$\widetilde{\omega} = \begin{cases} 0 & \text{if } z > \hat{\tau} + \varepsilon \\[2mm] 1 & \text{if } z < \hat{\tau} - \varepsilon \\[2mm] \dfrac{\hat{\tau} - z + \varepsilon}{2\varepsilon} & \text{if } \hat{\tau} - \varepsilon \leq z \leq \hat{\tau} + \varepsilon \end{cases} \qquad (2)$$

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[1] Since the small firms do not have any incentive to invest in the wastewater treatment technology in any case due to their inability to afford, we do not have to derive τ^* for the small firms.

Consider the range $[\tau - \varepsilon \le z \le \tau + \varepsilon]$, let us work out the critical proportion of firms that do not invest in the wastewater treatment technology needed to trigger the government to impose the effluent charge. It is required that the aggregate pollution contained in the effluent in the economy exceeds the limit, P, set by the government. Then, let $\overline{\omega}$ represents the critical proportion of large firms which do not invest in the wastewater treatment technology so that the non-investing firms are faced with the effluent charge if and only if $\omega > \overline{\omega}$:

$$\sigma e_S + (1 - \sigma)((1 - \overline{\omega})\lambda e_L + \omega e_L) = P. \qquad (3)$$

This reduces to:

$$\overline{\omega} = \frac{\dfrac{P - \sigma e_S}{1 - \sigma} - \lambda e_L}{(1 - \lambda)e_L}. \qquad (4)$$

It is important to note that $\overline{\omega}$ would exist only if $P > \sigma e_S + \lambda(1 - \sigma)e_L$, which implies that the limit on pollution should exceed the amount of pollution, discharged when all large firms invest in the wastewater treatment technology. The large firm believes that the government will levy the effluent charge if and only if $\widetilde{\omega} > \overline{\omega}$, that is:

$$\frac{\hat{\tau} - z + \varepsilon}{2\varepsilon} > \frac{\dfrac{P - \sigma e_S}{1 - \sigma} - \lambda e_L}{(1 - \lambda)e_L}. \qquad (5)$$

Equation (5) can be rearranged so that it yields:

$$z < \hat{\tau} + \varepsilon - \frac{(2\varepsilon)\left(\dfrac{P - \sigma e_S}{1 - \sigma} - \lambda e_L\right)}{(1 - \lambda)e_L}. \qquad (6)$$

Let $\dot{\tau}$ be the amount of effluent charge, above which sufficient proportion of large firms invest in the wastewater treatment technology. Thus, no effluent charge is levied. It follows from equation (6) that:

$$\dot{\tau} = \tau^* + \varepsilon - \frac{(2\varepsilon)\left(\dfrac{P - \sigma e_S}{1 - \sigma} - \lambda e_L\right)}{(1 - \lambda)e_L}. \qquad (7)$$

Conditional on τ, in order to determine each large firm's expected cost of investing in the wastewater treatment technology, there are two scenarios to be considered. First, when $\omega < \overline{\omega}$, the proportion of large firms, which decide not to invest in the technology, is sufficiently low, so the government does not levy the effluent charge. In this case, those firms, which did not invest in the wastewater treatment technology, could get away with the effluent charge. In the second scenario, consider the case in which $\omega \ge \overline{\omega}$. In this case, the proportion of large firms, which decide not to invest in the wastewater treatment technology, is too high such that the amount of pollution contained in the water exceeds the allowable limit. This triggers the government to levy the effluent charge on the small and large firms which do not invest in the wastewater treatment technology, given by:

$$T_S = \frac{(\sigma e_S + (1 - \sigma)[\lambda e_L + \omega(z)e_L(1 - \lambda)] - P)z}{1(1 - \sigma)\omega(z) + \sigma};$$

and

$$T_L = 1\frac{(\sigma e_S + (1 - \sigma)[\lambda e_L + \omega(z)e_L(1 - \lambda)] - P)z}{1(1 - \sigma)\omega(z) + \sigma},$$

respectively. The expected costs borne by large firm i, if it decides to invest or not invest in the wastewater treatment technology, are given in Table 1.

Table 1. Expected cost of investment decision

	$\omega \ge \overline{\omega}$	$\omega < \overline{\omega}$
Investing	$\displaystyle\int_{\tau_i - \varepsilon}^{\hat{\tau} + \varepsilon - \frac{(2\varepsilon)\left(\frac{P - \sigma e_S}{1 - \sigma} - \lambda e_L\right)}{(1 - \lambda)e_L}} \frac{1}{2\varepsilon}(I)\,dz$	$\displaystyle\int_{\hat{\tau} + \varepsilon - \frac{(2\varepsilon)\left(\frac{P - \sigma e_S}{1 - \sigma} - \lambda e_L\right)}{(1 - \lambda)e_L}}^{\tau_i + \varepsilon} \frac{1}{2\varepsilon}(I)\,dz$
Not investing	$\displaystyle\int_{\tau_i - \varepsilon}^{\hat{\tau} + \varepsilon - \frac{(2\varepsilon)\left(\frac{P - \sigma e_S}{1 - \sigma} - \lambda e_L\right)}{(1 - \lambda)e_L}} \frac{1}{2\varepsilon}T_L(z)\,dz$	0

From Table 1, it follows that the difference in the expected cost of large firm i, which received signal τ_i, between not investing and investing in the wastewater treatment technology is given by:

$$g(\tau_i, \hat{\tau}) = \int_{\tau_i - \varepsilon}^{\hat{\tau} + \varepsilon - \frac{(2\varepsilon)\left(\frac{P - \sigma e_S}{1 - \sigma} - \lambda e_L\right)}{(1-\lambda)e_L}} \frac{1}{2\varepsilon} \left(\frac{\left(\sigma e_S + (1-\sigma)\left[\lambda e_L + \left(\frac{\hat{\tau} - z + \varepsilon}{2\varepsilon}\right)e_L(1-\lambda)\right] - P\right)z}{(1-\sigma)\left(\frac{\hat{\tau} - z + \varepsilon}{2\varepsilon}\right) + \frac{\sigma}{l}} \right) dz - I. \tag{8}$$

In equilibrium, it requires that $\tau_i = \tau^*$ satisfies $g(\tau^*) = 0$, whereby the large firm i would be indifferent between investing and not investing in the wastewater treatment technology. Since all large firms are assumed to be identical, they will choose not to invest in the wastewater treatment technology if they received a signal below τ^* and will choose to invest if they received a signal above τ^*. It follows from the condition, $g(\tau^*) = 0$ that:

$$\int_{\tau^* - \varepsilon}^{\tau^* + \varepsilon - \frac{(2\varepsilon)\left(\frac{P - \sigma e_S}{1 - \sigma} - \lambda e_L\right)}{(1-\lambda)e_L}} \frac{1}{2\varepsilon} \left(\frac{\left(\sigma e_S + (1-\sigma)\left[\lambda e_L + \left(\frac{\tau^* - z + \varepsilon}{2\varepsilon}\right)e_L(1-\lambda)\right] - P\right)z}{(1-\sigma)\left(\frac{\tau^* - z + \varepsilon}{2\varepsilon}\right) + \frac{\sigma}{l}} \right) dz = I. \tag{9}$$

3. Comparative statics analysis on τ^*

In this Section, we conduct the comparative static analysis in order to analyse how the equilibrium threshold τ^*, changes when there is a change in the cost of investment in wastewater treatment technology I; the limit on pollution determined by the government P; the proportion of small firms σ; the amount of pollution discharged by firms not investing in abatement technology e_S, e_L; the difference in the effluent charge between the large and the small firms captured by l; and the amount of residual pollution despite the presence of wastewater treatment technology λ.

It is important to note that an increase in the equilibrium threshold τ^*, indicates that it is more difficult to ensure that the large firms invest in the wastewater treatment technology and the probability of investment is decreasing in τ^*. Equation (9) is used in the comparative static analysis that follows.

We begin by analysing the impact of a change in the cost of investment in wastewater treatment technology on the equilibrium threshold τ^*. When I increases, the costs borne by the firms increase. To offset this effect, the expected cost of not investing in the technology needs to rise, which means τ^* should increase. It follows that $\frac{\partial \tau^*}{\partial I} > 0$. This result suggests that an increase in the cost of investment in wastewater treatment technology makes it more difficult to achieve coordination among domestic firms.

Next, we analyse the impact of an increase in the limit on pollution P on the equilibrium threshold τ^*. When P increases, the expected cost of not investing in the wastewater treatment technology decreases. Thus, the government should increase τ^* to reduce this effect so $\frac{\partial \tau^*}{\partial P} > 0$. In other words, if the limit on pollution increases, the probability that the large firms invest in the wastewater treatment technology declines.

When the proportion of small firms σ, increases, the firms which will not invest in the wastewater treatment technology increases since the small firms cannot afford the expensive investment in such abatement technology in any case. This leads to an increase in the effluent charge that is imposed on the large firms that did not invest in the abatement technology, causing the expected cost of not investing in the technology to increase. To offset this effect, τ^* has to go down. It follows that $\frac{\partial \tau^*}{\partial \sigma} < 0$. In sum, the higher is the proportion of small firms (which do not invest in the wastewater treatment technology anyway), the higher will be the probability that the pollution limit be exceeded. Therefore, it is required that larger proportion of large firms should invest in the wastewater treatment technology to prevent the penalty from being too high.

What happens to τ^* if the amount of pollution discharged from the firms that do not invest in the wastewater treatment technology e_S and e_L increases?

When e_S (or e_L) increase, the total level of pollution discharged by small firms (or large firms) increases. Both of these eventualities will raise T_L, which is the total effluent charge that the government levies on the large firms that do not invest in the wastewater treatment technology, resulting in an increase in the expected cost of not investing in the technology. To offset such effect, τ^* has to go down, which implies that $\dfrac{\partial \tau^*}{\partial \sigma} < 0 \quad \dfrac{\partial \tau^*}{\partial e_j} < 0, \quad \text{for} \quad j = S, L.$

In what follows, we consider the impact of an increase in l on τ^*. As l increases, T_L increases. To counter this effect, the range over which this payment needs to be made has to decline, i.e., τ^* has to be lower. As more of the burden from effluent charges is transferred to the large firms, the more the large firms will be encouraged to invest in the abatement technology to reduce the risk of exceeding the pollution limit and get away with, being charged for not investing.

Last but not least, it is important to highlight that one needs to be careful with the comparative static analysis for the impact of changing the level of residual pollution λ on τ^*. When λ increases, the level of pollution discharged by firms, that invested in the wastewater treatment technology, increases. So, there is a higher risk that the pollution limit be exceeded and the expected cost for those firms which did not invest in the abatement technology would be higher. If the firm does invest in the technology, it will not be punished irrespective of the level of pollution contained in the river ecosystem. Therefore, when λ is higher, the large firms would invest in the abatement technology at a lower τ, which implies that τ does not need to be high, so $\dfrac{\partial \tau^*}{\partial \lambda} < 0$.

Proposition 1: The probability of investing in the wastewater treatment technology decreases (i.e., τ^* goes up) with the cost of investment in the technology I and the pollution limit P. The probability of investing in the abatement technology increases (i.e., τ^* goes down) with the proportion of small firms σ, the proportion of the burden passed onto the large firms l, the amount of pollution discharged by small and large firms which fail to invest in the technology e_S and e_L, and the residual pollution λ.

3. Design of optimal policy for effluent charge

The policy question that arises is how should the optimal effluent charge τ be chosen by the gov-

ernment. It is common knowledge that the small firms do not invest in the wastewater treatment technology regardless of the signal on τ, and that all large firms do not invest in the abatement technology if $\tau < \tau^*$ but choose to invest if $\tau > \tau^*$. In this paper, we argue that the objectives of the government are twofold: minimising the amount of pollution in the river ecosystem and caring about the payoffs of the domestic firms in the economy (including the survival of small firms).

For the small firms, if the aggregate amount of pollution in water exceeds the limit P, these firms will incur a cost $T_S(\tau, \omega)$. These small firms can bear this cost up to a certain degree. There exists a particular level of τ which will trigger the payoffs of the small firms to be negative, forcing them to close down their operations and leave the market. Let us denote such value of τ by τ_c. Given that the payoff for each small firm is given by $\mu_S - T_S$, it follows that τ_c is defined as the level of τ which satisfies the following equation:

$$\mu_S - \frac{\left(\sigma e_S + (1-\sigma)\left[\lambda e_L + \left(\dfrac{\tau^* - \tau_c + \varepsilon}{2\varepsilon}\right)e_L(1-\lambda)\right] - P\right)\tau_c}{l(1-\sigma)\left(\dfrac{\tau^* - \tau_c + \varepsilon}{2\varepsilon}\right) + \sigma} = 0. \quad (10)$$

We can conclude that $\tau_c > 0$ exists because, when $\tau_c = 0$, the *LHS* of equation (10) is strictly positive, and when $\tau_c \to 0$, $LHS \to -\infty$. From equation (10), it follows that (1) when $\tau < \dfrac{\mu_S[l(1-\sigma)+\sigma]}{\sigma e_S + (1-\sigma)e_L}$, small firms will survive even though there is no investment in wastewater treatment technology by the large firms $(\omega = 1)$; (2) when $\tau < \dfrac{\sigma \mu_S}{\sigma e_S + (1-\sigma)\lambda e_L}$, small firms will shut down even if all large firms invest in the wastewater treatment technology $(\omega = 0)$.

Proposition 2: There exists a level of effluent charge, τ_c, above which the small firms will shut down their operations and exit the market. The lower are μ_S and l, and the higher are λ, e_L and e_S, the more difficult it would be to enforce large firms to invest in the wastewater treatment technology.

Given the government's objective of ensuring the survival of small firms which cannot afford to invest in the wastewater treatment technology, it follows that τ cannot exceed τ_c. All large firms

will invest so long as $\tau_c > \tau^* + \varepsilon$. Therefore, τ should be the lower of $\left(\tau_c, \ \tau^* + \varepsilon\right)$. Minimising the amount of pollution requires that all large firms invest in the wastewater treatment technology, and this can be achieved if $\tau_c < \tau^* + \varepsilon$. In order to ensure the survival of small firms, while increasing the effluent charge to encourage large firms, to invest in the wastewater treatment technology τ_c, should be higher. Small firms will be able to survive the higher levels of τ so long as they have more profits (larger μ_S) more efficient wastewater treatment technology (lower λ, e_L and e_S) and more of the burden from effluent charge is borne by the large firms if the pollution exceeds the limit (higher l).

We observe that if the limit on pollution is too strict, the small firms are unable to survive, so, they have to shut down their operation. If such limit is sufficiently lax, this would result in an increase in the amount of pollution because the small firms could continue to produce without using the wastewater treatment technology to deal with the pollution contained in the effluent and the large firms are encouraged not to invest in the abatement technology. If the government is determined to reduce the water pollution without driving the small firms out of the market, it should subsidise the small firms for their investment in the wastewater treatment technology with an amount $I - \mu_S$ and set the pollution limit at λe so that, unless all domestic firms invest in the abatement technology, those which do not invest will be penalised.

Conclusion

We have considered the problem of coordination failure among firms to invest in wastewater treatment technology. The government introduces an effluent charge to ensure that firms invest in this technology. The higher the proportion of firms which do not invest, the higher will be the probability of being charged, and the higher will be the cost. The model shows that the more efficient the technology, the stiffer should be punishment to ensure investment. The model shows that the probability of investment in the technology by the large firms increases with the proportion of small firms and the pollution emitted by both small and large firms. The probability of investment goes down with: the cost of investment; the efficiency of the technology; and the level of water pollution that the government will allow. We also consider the fact that small firms cannot survive if the charge is too high, and the government cares not only about the environment but also about the survival of firms. The paper explains why the government cannot be too strict in implementing environmental policy if there are too many small firms whose mere survival would be threatened by such strictness.

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