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Abstract

We model an economy where imperfectly competitive firms choose whether to employ a dirty technology and pay an emission tax or employ a clean technology and incur the cost of its adoption. Bureaucrats who are entrusted with the task of monitoring the emissions of each firm, are corruptible in the sense that they may accept bribes in order to mislead authorities on the firms' actual emissions. Market entry is an important element in the relation between corruption and pollution. Particularly, the incidence of corruption increases the number of entrants in the market, while the bureaucrats' incentives to be corrupt are higher in a market with more competitors. We find multiple equilibria where both corruption and pollution are either high or low.

Keywords: Corruption; Pollution; Market entry

JEL Classification: L13; Q53; Q58

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1 Introduction

According to Transparency International, corruption can be defined as "the abuse of entrusted power for private gain" and can be classified into two broad categories – 'grand' corruption and 'petty' corruption. The former involves the exploitation of power by individuals in the higher ranks of public administration, e.g., the government, whereas the latter entails the exploitation of office by low- and mid-level public officials, e.g., the bureaucrats.[1] By its very nature, corruption can infringe on a country's social, economic as well as political domains, while its effects can be potentially far reaching. In this paper, we focus on an aspect whose relation with corruption has been receiving increased attention in recent years, mainly due to the current debate over climate change and the challenges that policy makers face in order to address it. This aspect is the quality of the natural environment.

On the outset, identifying a link between corruption and environmental quality seems to be straightforward. For example, grand corruption can determine the existence or the stringency of various environmental policies (such as pollution controls) whereas petty corruption can affect their effectiveness and implementation. Indeed, there is ample empirical support for these arguments. Fredriksson and Svensson (2003), Welsch (2004) and Cole (2007) provide cross-country evidence for the detrimental effect of corruption on the strictness of environmental regulations as well as their effectiveness. In her cross-country econometric study, Ivanova (2011) finds that even though countries with more effective environmental regulations report higher emissions, their actual emission levels are lower. This result is indicative of the fact that one of the consequences of corruption is that emissions tend to be significantly under-reported. Hubbard (1998) and Oliva (2012) employ empirical analyses to argue that the effectiveness of vehicle emission controls is significantly reduced as a result of corrupt activities in some inspection centres. Koyuncu and Yilmaz (2009) use a cross-country analysis to link corruption with deforestation, arguing that practices such as the under-declaration of the number of trees cut in public forests or the illegal sale of harvesting permits, have contributed significantly to the depletion of forest resources.[2]

[1] http://www.transparency.org/whoweare/organisation/faqs_on_corruption#defineCorruption.
[2] A link between corruption and illegal logging is also established in Burgess *et al.* (2012).

The aforementioned mechanisms identify what can be considered as the direct effect of corruption on the quality of the environment. Nevertheless, we can think of other indirect mechanisms through which corruption can impinge on the environment. For instance, consider GDP per capita. It is now widely accepted that corruption can be an unfavourable factor in the determination of a country's per capita income (Mauro 1995; Aidt 2009); therefore it can affect pollution through its effect on GDP per capita, even for a given set of environmental regulations. Intuitively, this effect is opposite to the direct one that we described previously, because the adverse impact of corruption on income should mitigate the extent of environmental degradation – after all, pollution is, to a large extent, a by-product of economic activity. Despite this fact, empirical evidence has shown that even after controlling for this indirect effect, the overall effect of corruption on pollutant emissions is positive. This is, for example, the outcome in the empirical investigation of Welsch (2004). In Cole (2007) the results are more ambiguous; yet the positive effect of corruption on pollution still materialises for the sub-sample of high income countries.[3]

Our paper seeks to promote our understanding of the issue by drawing attention to a previously unexplored indirect mechanism through which corruption impinges on environmental quality. This mechanism is related to market entry. We build a model where firms can produce goods using either a relatively dirty technology or a relatively clean one. Firms that employ the former are liable to an emission tax/penalty; firms that employ the latter are exempt from the tax, but have to incur the cost of its adoption. Bureaucrats are entrusted with the task of verifying the technology employed by firms and advise the government on the appropriate action, i.e., whether to impose the tax or not. Nevertheless, there is a moral hazard problem given that, in exchange for a bribe, bureaucrats may offer to firms that employ the dirty technology the opportunity of fabricating their true circumstances, thus misleading the government by advising against the imposition of the emission tax.

The characteristics of the model's equilibrium are the following. On the one hand, corruption increases the number of entrants in the industry since the opportunity of bribing bureaucrats to avoid the tax burden associated with the use of the costless, but more

[3] Another indirect mechanism on the corruption-pollution nexus is presented in Biswas *et al.* (2012). They find that corruption can affect environmental quality by increasing the activities of the shadow economy – the part of the economy whose activities cannot be regulated by environmental laws.

polluting, technology reduces the expected (fixed) operating costs. On the other hand, a larger number of competing firms increases the bureaucrats' incentives to be corrupt, simply because a market with more firms offers a larger pool of potential bribe payers, thus increasing the expected benefits of being corrupt. Given these characteristics, the model generates multiple equilibria. Depending on parameter configurations, the equilibrium may be characterised by either a regime where bureaucrats are corrupt and more firms compete in the market, or a regime where none of the bureaucrats is corrupt and the market is comprised of fewer competitors. Furthermore, there is a possibility of equilibrium indeterminacy, as there are parameter configurations for which any of these two regimes represents a possible equilibrium outcome. On the whole, there are two distinct channels through which corruption can affect pollution. On the one hand, corruption increases the fraction of firms that use the relatively dirty technology – a direct effect that is corroborated by empirical evidence to which we alluded earlier. On the other hand, corruption increases the number of firms that compete in the market and produce output, thus increasing the amount of total emissions for given technology choices. This is an indirect effect that actually exacerbates the detrimental impact of corruption on environmental quality. It should be noted that the innovative aspect of our indirect channel, i.e., the positive effect of corruption on industry entry, finds empirical support in the recent study of Dreher and Gassebner (2013) who present evidence that corruption facilitates entry in economies where market activity is significantly regulated.

All in all, our model raises awareness to a previously unexplored mechanism that contributes to the understanding of the empirically-supported, positive relation between corruption and pollutant emissions. In relation to the existing literature, our paper is closely connected to theoretical contributions that have introduced either grand or petty corruption (or both) into frameworks where environmental regulations call for emission reporting and monitoring (e.g., Acemoglu and Verdier 2000; López and Mitra 2000; Damania 2002; Damania *et al.* 2004).[4] Despite the wealth of results and interesting implications emerging from these studies, the importance of market entry has eluded their attention as none of them have explicitly considered the repercussions of market structure in their analyses. Our

[4] For theoretical contributions that introduce the possibility of emission under-reporting but abscond from the issue of corruption, see Harford (1987) and Malik (1993) among others.

contribution is that we clearly identify market entry as an important element in the relation between corruption and pollution.

The remainder of our analysis is organised as follows. In Section 2 we outline the characteristics of the market in which firms produce and supply their products. Section 3 analyses the incentives for corruption by both firms and bureaucrats. In Section 4 we use the results of the previous section in order to identify the effect of corruption on pollution. Section 5 shows that the results remain the same even after the removal of one of the model's restrictions regarding the relation between the cost of technology adoption and the environmental tax. In Section 6 we conclude.

2 An Overview of the Market

The purpose of this section is to present a brief overview of the characteristics that describe the demand and the supply side of our economic set-up.

2.1 Demand

Consider an economy where consumers purchase units of a homogeneous good that is supplied by imperfectly competitive firms. There is a mass of $k > 0$ consumers, each one indexed by i. Each consumer decides whether to purchase one unit of the good or not. Consuming the good entails a utility of u_i, a variable that is uniformly distributed across consumers over the interval $[0, k]$ with density function $f(u_i) = \frac{1}{k}$. Denoting the price of the homogeneous good by p, it follows that each consumer's surplus is

$$s_i = u_i - p \,. \tag{1}$$

A consumer i will purchase the good, if and only if the surplus associated with its consumption is non-negative, i.e., iff $s_i \geq 0$. Using (1), it is straightforward to establish that the consumers who will buy and consume units of the good are those consumers whose preferences satisfy $u_i \in [p, k]$. Therefore, the fraction of consumers purchasing the good is equal to

$$\int_p^k f(u_i)du_i = \frac{k - p}{k} \,. \tag{2}$$

We can use Equation (2) to get the aggregate demand function

$$Q = \frac{k - p}{k} k = k - p, \tag{3}$$

where Q denotes the total demand for the product. The aggregate demand function is the sum of consumption expenditures by those consumers with non-negative surplus. Naturally, the demand is inversely related to the good's price because a higher price supresses the number of potential consumers who can get a non-negative surplus from its consumption. In what follows, we will find useful to undertake the analysis in terms of the inverse demand function. Using (3), the inverse demand function can be written as

$$p = k - Q. \tag{4}$$

2.2 Supply

Now let us consider the characteristics of the industry that supplies the good. Denote the number of firms that compete in the market by n. Each firm, indexed by j, produces and supplies q_j units of the good. Market clearing requires that $Q = \sum_{j=1}^{n} q_j$. Therefore, we can use Equation (4) to express a firm's variable profit, denoted v_j, according to

$$v_j = \left(k - \sum_{j=1}^{n} q_j \right) q_j - m q_j, \tag{5}$$

where $m > 0$ is the per unit cost of production.[5] Since the good supplied from the industry is homogeneous, it is useful to think of the firms as Cournot competitors that choose the quantity they produce in order to maximise their variable profit. Therefore[6]

$$\frac{\partial v_j}{\partial q_j} = 0 \Leftrightarrow k - \sum_{j=1}^{n} q_j - q_j^* - m = 0. \tag{6}$$

Combining the market clearing condition $Q = \sum_{j=1}^{n} q_j$ with (4) and (6), it follows that the equilibrium is symmetric; that is, $q_j^* = q^* \; \forall j$. Using (6), we get

$$q^* = \frac{k - m}{1 + n}. \tag{7}$$

[5] We assume $m < k$ so that each firm produces a strictly positive quantity of output (see Equation 7).

[6] It is can be easily checked that the sufficient condition for a maximum holds, i.e., $\frac{\partial^2 v_j}{\partial q_i^2} = -2 < 0$.

Given $Q = nq^*$, we can substitute (7) in (4) to get

$$p = \frac{k + nm}{1+n}. \tag{8}$$

The equilibrium variable profit of a firm equals $v = (p - m)q^*$. Substituting Equations (7) and (8), we get

$$v = \left(\frac{k - m}{1+n}\right)^2. \tag{9}$$

As expected, the firm's variable profit is lower when the number of competitors in the market is higher. With a higher number of competitors, total supply (i.e., nq^*) increases. For the market to clear, the price of the good has to fall in order to allow more consumers to enjoy a non-negative surplus from its consumption. The reduction in price has a detrimental effect on each firm's variable profit.

3 Environmental Tax, Corruption Incentives, and Entry

There are two technologies available for each firm to choose.[7] The relatively dirty technology emits $\overline{e} > 0$ pollutants per unit of production and can be adopted at zero cost. However, firms that employ this technology are liable to a lump-sum environmental tax/penalty, equal to $t > 0$. The relatively clean technology emits $\underline{e} < \overline{e}$ pollutants per unit of production and its implementation relieves the firm from the obligation to pay the tax t. Nevertheless, its adoption is costly in the sense that it requires a fixed cost c_j. This cost is random and realised only after firms make their decision to operate in the industry. It is also independently and identically distributed across firms. For simplicity, we consider a uniform distribution for c_j. Specifically, c_j is distributed on the interval $[0, x]$ with a probability density function $f(c_j) = \frac{1}{x}$.

The government cannot directly observe the technology of each firm. For this reason, it delegates this task to bureaucrats who monitor firms and verify the technology they employ. These officials are instructed to inform the government on the technology adopted by each

[7] Other analyses of environmental regulation and emission reporting have employed the assumption of a binary technology choice. See, for example, Malik (1993).

firm and therefore advise on whether a tax should be imposed or not. We assume that the government hires δ bureaucrats, where $\delta < n$, and offers a salary $\omega > 0$ to each of them, in exchange for his services. All firms will have their technology verified, i.e., each official will monitor $\frac{n}{\delta}$ firms.

The timing of the events that we consider is the following. In the first stage, potential entrants decide whether to incur the fixed cost of entry which allows them to compete in the industry. This fixed cost is equal to $\varphi > 0$. During the second stage, each firm chooses which technology to employ, a choice that is monitored and verified by a bureaucrat. We assume that bureaucrats are able to verify the actual choice of technology, i.e., firms cannot mislead them with regard to the technology they have adopted. However, as we shall see later, firms and bureaucrats may enter into an illegal agreement to conceal the true circumstances (regarding the technology choice) from the government. In the third stage, firms produce the goods that they supply in the market. As it is evident, the fixed nature of all the costs associated with entry (i.e., φ) and technology choice (i.e., either the adoption cost or the environmental tax) means that the decision on how much to produce is not directly affected by the choice of technology.

We assume that the upper bound of the distribution of the adoption cost is high enough so that any effort to set the environmental tax to induce adoption of the clean technology whatever the realisation of c_j (i.e., when $t \geq x$) will deter entry for everyone. This outcome can be possible since firms make their entry decisions based on an expectation for c_j (recall that the actual cost is realised after entry takes place).[8] Our current assumption seems to describe the more realistic scenario. The alternative assumption would imply that the government can entice every firm into the adoption of the less polluting technology, simply by setting the environmental tax arbitrarily high. Yet this outcome would be at odds with actual experience given that there are hardly any industries in which all firms operate the cleanest possible production methods. Despite these arguments, in Section 5 we relax this restriction and show that our results remain intact.

[8] Formally, this may happen if $\frac{k-m}{\sqrt{\varphi + (x/2)}} < 1$, a condition that we assume to hold.

Now, let us consider a firm that has decided to operate in the market. During the second stage, the firm will adopt the clean technology as long as $v - c_j \geq v - t \Leftrightarrow t \geq c_j$. Given that $t < x$ holds, a firm j will be willing to use the clean technology, as long as

$$c_j < t. \tag{10}$$

Given (10), firms which face $c_j \in [0, t)$ will opt for the adoption of the clean technology (i.e., the one with emission rate $\underline{e}$) whereas firms who face $c_j \in [t, x]$ will choose the more polluting technology (i.e., the one emitting $\overline{e}$ pollutants per unit of output produced) and pay the environmental tax.

Now let us consider the choice of a firm which considers entry during the first stage. The expected profit is given by

$$\pi_j = v - \int_0^t c_j f(c_j) dc_j - t \int_t^x f(c_j) dc_j = v - \frac{t^2}{2x} - \frac{t(x-t)}{x} = v - t + \frac{t^2}{2x} = v - \mu \equiv \pi, \tag{11}$$

where

$$\mu = \frac{t(2x-t)}{2x}. \tag{12}$$

Potential entrants will wish to pay the fixed cost of entry and operate in the industry as long as $\pi \geq \varphi$. Therefore, given $\frac{\partial \pi_j}{\partial n} = \frac{\partial v}{\partial n} < 0$, the equilibrium number of firms will be determined by the zero profit condition $\pi = \varphi$. Using (9) and (11), it follows that the equilibrium number of firms can be calculated as

$$n^* = \frac{k-m}{\sqrt{\varphi + \mu}} - 1. \tag{13}$$

The result in Equation (13) gives the equilibrium number of competitors in the scenario where both the parties that are involved in the choice and verification of the technology employed, i.e., firms and bureaucrats, behave honestly. Nevertheless, the delegation of monitoring to a third party generates a moral hazard issue that could lead to the following situation. Suppose that a bureaucrat would be willing to accept a bribe in order conceal the actual circumstances relevant to the technology choice of the firm he monitors. Particularly, by paying a bribe $b > 0$ to the official, the firm can avoid paying the environmental tax despite the fact that it can choose not to incur the cost of adoption of a cleaner production method. Instead, the official who accepts the bribe will report that the firm employs the less polluting production technology, while in reality this is not the case. Of course, the risk underlying this illegal collusion is that it may be eventually detected by the authorities. For the firm that is subsequently proven guilty of such misdemeanour, the penalty is that it will have to pay the environmental tax associated with the use of a dirty technology.

Now consider a firm that is monitored by an official who is corrupt in the sense that he is willing to accept the bribe. Furthermore, denote $\sigma \in (0,1)$ to be the probability that the authorities will eventually detect the fraudulent agreement between the firm and the official. The expected profit for the firm is

$$v - (b + \sigma t), \tag{14}$$

i.e., the amount that remains from the variable profits, after subtracting the bribe and the expected penalty in case the firm is apprehended. Of course, if the firm decides to adopt the clean technology, there is no need to pay the bribe and its profit will be $v - c_j$. It follows that a firm j will be willing to adopt the less polluting technology, as long as

$$c_j < b + \sigma t \equiv \hat{c}. \tag{15}$$

Given (15), firms with $c_j \in [0, \hat{c})$ will choose the clean technology, whereas firms with $c_j \in [\hat{c}, x]$ will choose the more polluting technology and bribe bureaucrats in order to deceive government authorities on their actual choice. Therefore, the number of firms which are willing to engage in a fraudulent collusion with a bureaucrat can be found from

$$n \int_{\hat{c}}^{x} f(c_j) dc_j = n \frac{x - \hat{c}}{x} = n \frac{x - (b + \sigma t)}{x}. \tag{16}$$

As it is evident from (16), a higher bribe will reduce the number of firms that are willing to collude with the bureaucrat in concealing their true circumstances from the authorities. This is a quite intuitive result. A higher bribe will reduce the expected profit when the firm opts for adopting the dirty technology and bribes the corrupt official in order to mislead the government. As a result, more firms will find the adoption of the clean technology to be a more desirable option in terms of profitability.

Now consider a bureaucrat who contemplates his utility for the scenario where he engages in the type of fraudulent collusion that we described above. In addition to his salary ω, there is also the opportunity to earn illegal rents from the firms that are willing to bribe him in order to mislead the authorities. Recall that each bureaucrat will monitor $\frac{n}{\delta}$ firms.

Taking into account the previous analysis and discussion, the probability that a firm will be willing to offer him a bribe is $\int_{\hat{c}}^{x} f(c_j)dc_j = \frac{x-(b+\sigma t)}{x}$. Furthermore, recall that the government will detect cases of fraudulent behaviour with probability σ. With regard to the bureaucrat, the penalty for such malfeasance is that he is dismissed without pay and he also loses all his ill-gotten gains. Given this discussion, the expected utility λ^C of a corrupted official is

$$\lambda^C(b;n) = (1-\sigma)\left[\omega + \frac{x-(b+\sigma t)}{x}\frac{n}{\delta}b\right]. \tag{17}$$

Naturally, the bureaucrat will demand a bribe that maximises his expected utility. When deciding the bribe that he will ask in order to conceal the true characteristics of the firm he monitors, he will have to take account of two opposing effects on his expected utility. On the one hand, a higher bribe will directly increase the amount of ill-gotten gains. On the other hand, it will reduce the potential pool of firms out of which the official can extract illegal rents. This is because some of these firms will find it more advantageous to actually adopt the cleaner technology (thus having no need to bribe officials at all) if the bribe is too high. In addition to these considerations, note that the maximum bribe that a bureaucrat can demand is equal to $(1-\sigma)t$. Any bribe above this level would imply that those firms for which the adoption cost is too high to consider the implementation of the clean technology, would prefer to have their circumstances truthfully reported and subsequently pay the environmental tax, rather than paying the bureaucrat in order to conceal their information.

Let $b^* = \arg\max \lambda^C(b;n)$. We can use (17) and set $\frac{\partial \lambda^C(b;n)}{\partial b} = 0$ to obtain[9]

$$b^* = \frac{x-\sigma t}{2}. \tag{18}$$

This result, combined with the preceding discussion, reveals that the optimal bribe is given by $\min\{b^*,(1-\sigma)t\}$. In order to pin down the chosen bribe to a unique value, we are going to make a parametric assumption that will guarantee the interior solution for b. The details are summarised in

[9] It is $\frac{\partial^2 \lambda^C(b;n)}{\partial b^2} = \frac{-2n}{x\delta} < 0$, meaning that the sufficient condition for a maximum holds.

Lemma 1. *Assume that* $\frac{x}{2-\sigma} < t < x$ *holds. Then the bribe that is optimal for a bureaucrat is given by* b^*.

Proof. It is sufficient to show that $b^* < (1-\sigma)t$. Using Equation (18), this condition is equivalent to

$$\frac{x-\sigma t}{2} < (1-\sigma)t \Rightarrow$$
$$x < 2(1-\sigma)t + \sigma t \Rightarrow$$
$$x < (2-\sigma)t,$$

which holds by assumption. □

Let us discuss the characteristics of the result in (18). Firstly, the bribe is increasing in the upper bound of the distribution of technology adoption costs. The intuition is that x increases the expected cost of technology adoption, thus rendering bribery as a potentially more advantageous option for firms. Secondly, the bribe is decreasing in the environmental tax. Despite the fact that this effect seems counter-intuitive, it actually makes sense in this context. From a firm's point of view, a higher tax increases the expected cost of being caught engaging in an illegal agreement with a bureaucrat. As we discussed earlier, firms that are eventually apprehended will be forced to pay the tax. This reduces the incentive to collude; therefore the bureaucrat can extract fewer rents from the potential agreement with the firm.[10]

Now, let us substitute (18) in (17) in order to write the expected utility of a corrupted official as

$$\lambda^C(n) = (1-\sigma)\left[\omega + \frac{(x-\sigma t)^2}{4x}\frac{n}{\delta}\right]. \tag{19}$$

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[10] Assuming that $t < \frac{x}{2-\sigma} < x$ holds, would imply that the bribe demanded by the bureaucrat is equal to $(1-\sigma)t$. Indeed, this would maximise the expected utility of a bureaucrat, given that the firm's participation constraint must be satisfied. Nevertheless, a look at (10) and (15) reveals that in this case, whether there is corruption or not will not have any implications for the number of firms that adopt the cleaner technology. Therefore equilibrium entry, aggregate production and (as we shall see in a latter section) pollution would be the same whether there is corruption among bureaucrats or not. As this is a trivial and uninteresting case, we rule it out by imposing the condition in Lemma 1.

Given the characteristics of our model, an official who decides to behave honestly will enjoy utility λ^H equal to

$$\lambda^H = \omega\,, \tag{20}$$

i.e., he will not accept bribes from firms which may be willing to offer them and his income will be composed only of his salary. Of course, it is ultimately the choice of the bureaucrat whether to behave honestly or to take advantage of his position and seek to improve his income by means of bribe-taking. The decision will involve the comparison of the utilities in (19) and (20), a process that allows us to infer

Lemma 2. *There is a critical level* $\hat{n}$ *such that:*

i. *For* $n < \hat{n}$*, none of the bureaucrats is corrupt;*

ii. *For* $n > \hat{n}$*, all bureaucrats are potentially corrupt.*

Proof. Setting $\lambda^H = \lambda^C(n)$ we get $\hat{n}$ such that

$$(1-\sigma)\left[\omega + \frac{(x-\sigma t)^2}{4x}\frac{\hat{n}}{\delta}\right] = \omega \Rightarrow$$

$$\hat{n} = \frac{4x\sigma\omega\delta}{(x-\sigma t)^2(1-\sigma)}\,. \tag{21}$$

Hence, the result of Lemma 1 follows from the fact that $\dfrac{\partial\lambda^C(n)}{\partial n} > 0$ and $\dfrac{\partial\lambda^H}{\partial n} = 0$ according to (19) and (20) respectively. □

Among other factors, the number of firms that compete in the industry is a significant determinant of a bureaucrat's decision on whether to be corrupt or honest. The intuition is as follows. From a bureaucrat's point of view, a higher number of competitors will increase the pool of potential bribe payers. Consequently, his expected utility increases relative to the corresponding utility that he enjoys if he decides to behave honestly. In other words, a higher number of firms makes it more likely that the bureaucrat will ultimately seek to take advantage of his position and accept bribes in order to conceal information from the government.

Now let us try to understand the implications of corruption for equilibrium entry. For a firm that contemplates entry during the first stage, the expected profit is

$$\pi_j = v - \int_0^{\hat{c}} c_j f(c_j) dc_j - (b+\sigma t)\int_{\hat{c}}^{x} f(c_j) dc_j = v - \frac{\hat{c}^2}{2x} - \frac{(b+\sigma t)(x-\hat{c})}{x}. \tag{22}$$

Substitution of (15) in (22) yields

$$\pi_j = v - \frac{(b+\sigma t)^2}{2x} - (b+\sigma t) + \frac{(b+\sigma t)^2}{x} = v - (b+\sigma t) + \frac{(b+\sigma t)^2}{2x}, \tag{23}$$

to which we can substitute (18) and derive

$$\pi_j = v - \frac{x+\sigma t}{2} + \frac{(x+\sigma t)^2}{8x} = v - \frac{x+\sigma t}{2}\left(1 - \frac{x+\sigma t}{4x}\right) = v - \gamma \equiv \pi, \tag{24}$$

where

$$\gamma = \frac{(x+\sigma t)(3x-\sigma t)}{8x}. \tag{25}$$

Taking account of the fixed cost of entry, firms will have the incentive to operate in the industry as long as as $\pi \geq \varphi$ holds. Once more, the equilibrium number of firms will be determined by $\pi = \varphi$. Using (9) and (25), we can calculate equilibrium entry according to

$$n^{**} = \frac{k-m}{\sqrt{\varphi+\gamma}} - 1. \tag{26}$$

The result in Equation (26) is analogous to Equation (13), the only difference being that now entry has been determined in an environment where bureaucrats are potentially corrupt, i.e., willing to accept bribes in order to mislead authorities on the actual implementation of technology by firms. A straightforward comparison between these two cases leads to

Lemma 3. *Equilibrium entry is higher in the presence of corruption among bureaucrats. That is,* $n^{**} > n^*$.

Proof. Inspection of (13) and (26) reveals that $n^{**} > n^*$ holds, as long as $\gamma < \mu$. Indeed, we can use (12) and (25) to investigate the conditions for which

$$\frac{(x+\sigma t)(3x-\sigma t)}{8x} \leq \frac{t(2x-t)}{2x} \Rightarrow$$

$$3x^2 + 2x\sigma t - (\sigma t)^2 \leq 8xt - 4t^2 \Rightarrow$$

$$3x^2 - 2xt(4-\sigma) + t^2(4-\sigma^2) = L(t) \leq 0\,, \tag{27}$$

holds. Taking the first and second derivatives of (27) with respect to t, we get $L'(t) = -2x(4-\sigma) + 2t(4-\sigma^2)$ and $L''(t) = 2(4-\sigma^2) > 0$ respectively. By virtue of the conditions imposed in Lemma 1, the minimum possible tax satisfies $t = \frac{x}{2-\sigma}$. Substituting this in (27) yields

$$x^2\left[3 - \frac{2(4-\sigma)}{2-\sigma} + \frac{4-\sigma^2}{(2-\sigma)^2}\right] = \frac{x^2}{(2-\sigma)^2}\left[3(2-\sigma)^2 - 2(4-\sigma)(2-\sigma) + 4 - \sigma^2\right] = 0\,. \tag{28}$$

Despite the fact that the derivative $L'(t)$ cannot be signed with certainty, the positive second derivative together with (28) imply that, as long as (27) holds for the maximum possible tax (that is $t = x$), then it must hold for any $t \in \left(\frac{x}{2-\sigma}, x\right)$. This is because $L(t)$ is U-shaped, thus it admits its highest possible values at the boundaries of the domain $t \in \left(\frac{x}{2-\sigma}, x\right)$. Substituting $t = x$ in (27) we get

$$3x^2 - 2x^2(4-\sigma) + x^2(4-\sigma^2) \Rightarrow$$

$$x^2(-1 + 2\sigma - \sigma^2) \Rightarrow$$

$$-x^2(\sigma - 1)^2 < 0 \tag{29}$$

The preceding analysis shows that the expression in (27) holds as a strict inequality, thus completing the proof of the proposition. □

The underlying intuition behind Lemma 3 is simple. Bureaucrats demand a bribe that will deter some firms from the implementation of the cleaner production method, simply because those firms find it less costly to bribe bureaucrats in order to conceal their actual choice of technology. In other words, the incidence of corruption offers opportunities that reduce the expected fixed costs of operating in the industry. As a result, the expected total profit increases, thus enticing more firms to compete in the market.

4 Pollution

The purpose of this section is to gather all the results from the preceding analysis, and combine them in order to identify the implications of corruption for pollution. In this context, pollution corresponds to aggregate emissions, i.e., the total emissions resulting from the production activities of all the firms that supply the economy's consumption good. On the outset, we expect corruption to affect pollution through two distinct mechanisms. Firstly, corruption affects total production, and therefore total emissions, through its impact on equilibrium entry. Secondly, corruption also affects the fraction of these competitors that actually opt for the adoption of the less polluting production process. With respect to the former effect, we can use the analysis of the previous section to derive

Proposition 1. *Consider the composite parameter terms* $r = \frac{k - m}{\sqrt{\varphi + \gamma}}$, $z = \frac{k - m}{\sqrt{\varphi + \mu}}$ *and* $a = \frac{4x\sigma\omega\delta + (x - \sigma t)^2(1-\sigma)}{(x - \sigma t)^2(1-\sigma)}$. *Then, the following summarises all the possible equilibria in terms of corruption and entry:*

i. *For* $r < a$, *none of the bureaucrats is corrupt and equilibrium entry is characterised by* n^*;

ii. *For* $z > a$, *all bureaucrats are potentially corrupt and equilibrium entry is characterised by* n^{**};

iii. *For* $z < a < r$ *both cases where either none of the bureaucrats is corrupt and the number of firms is* n^*, *or all bureaucrats are potentially corrupt and the number of firms is* n^{**}, *are possible equilibria.*

Proof. Consider $r < a$. By virtue of (21) and (26), this implies that $n^{**} < \hat{n}$. Given Lemmas 2 and 3, an equilibrium with corruption cannot exist because, under all circumstances, equilibrium entry falls in the region where bureaucrats find it optimal to behave honestly. But then, the only possible solution for entry is given by (13), a result that is verified by the fact that, as long as $n^{**} < \hat{n}$, it is certainly true that $n^* < \hat{n}$. Now consider $z > a$ which, by virtue of (13) and (21), implies that $n^* > \hat{n}$. In this case, we can allude to Lemmas 2 and 3 in order to establish that an equilibrium without corruption does not exist. This is because under all circumstances, equilibrium entry falls in the region where bureaucrats find it optimal to be corrupt when such opportunity is given to them. But then, the only possible solution for entry is given in Equation (26). Indeed, this conjecture is verified by the fact that, as long as $n^* > \hat{n}$, then it is certainly true that $n^{**} > \hat{n}$. Finally, the previous discussion reveals that, insofar as $\underset{\sim}{z} < a < r$ holds, we cannot find an argument that will pin down a unique equilibrium. Instead, both scenarios represent a possible equilibrium outcome, because $n^* < \hat{n}$ is consistent with an equilibrium where no bureaucrat is corrupt while, at the same time, $n^{**} > \hat{n}$ is also consistent with an equilibrium where officials will be corrupt, whenever such opportunity arises. □

The interpretation of these results is the following. When structural parameters are conducive to a situation where bureaucrats will certainly refuse any offer of a bribe, potential entrants know that they will not be able to mislead authorities in a way that will allow them to avoid paying the environmental tax, despite their use of a more polluting, but costless, technology. Nevertheless, when structural parameters guarantee that bureaucrats will be willing to accept bribes when such prospect arises, potential entrants see this as an opportunity of greater profitability, simply because they know that the expected cost of technology choice is lower. It is the expectation of higher expected profits that entices a potentially higher number of competitors in the industry. Indeterminacy emerges under parameter configurations that generate a case of self-fulfilling prophecies. If potential entrants expect that bureaucrats will (will not) accept bribes, the resulting entry in the industry will be sufficient to motivate bureaucrats to seek (not to seek) illegal rents through bribery, thus verifying the initial expectation.

Next, we delve into the implications of corruption for technology choice. Let us denote the fraction of firms choosing the relatively dirty technology by θ, meaning that $1-\theta$ is the fraction of firms adopting the less polluting technology. We begin with the case where there is no corruption among bureaucrats, for which we can use (10) to obtain these fractions as

$$\theta^* = \int_t^x f(c_j)dc_j = \frac{x-t}{x} \text{ and } 1-\theta^* = \int_0^t f(c_j)dc_j = \frac{t}{x}. \tag{30}$$

If we use (15) and (18), we can derive the corresponding shares in the scenario where bureaucrats are potentially corrupt. That is,

$$\theta^{**} = \int_{\hat{c}}^x f(c_j)dc_j = \frac{x-\sigma t}{2x} \text{ and } 1-\theta^{**} = \int_0^{\hat{c}} f(c_j)dc_j = \frac{x+\sigma t}{2x}. \tag{31}$$

These results allow us to derive

Lemma 4. *Corruption reduces the fraction of competing firms that adopt the less polluting technology, i.e.,* $\theta^{**} > \theta^{*}$.

Proof. Using (30) and (31), it can be easily checked that $\theta^{**} > \theta^{*}$ holds, as long as $t > \frac{x}{2-\sigma}$. This condition applies by virtue of Lemma 1. □

Denote pollution by S. As we indicated earlier, pollution corresponds to the emissions resulting from the production activities of all competing firms in the market. Formally,

$$S = \theta nq\overline{e} + (1-\theta)nq\underline{e} = Q[\theta\overline{e} + (1-\theta)\underline{e}], \tag{32}$$

where $Q = nq$. Using the implications from the preceding analysis, our next result comes in the form of

Proposition 2. *Corruption is associated with greater pollution.*

Proof. We can use Equation (7) to write aggregate production as $Q = \frac{n(k-m)}{1+n}$, an expression for which we can check that $\frac{\partial Q}{\partial n} > 0$ holds. Furthermore, we can use (32) to establish that $\frac{\partial S}{\partial Q} > 0$ and $\frac{\partial S}{\partial \theta} = Q(\overline{e} - \underline{e}) > 0$. Thus, we can allude to the results of Lemmas 3 and 4 in order to establish that corruption leads to higher pollution. □

Corruption increases pollution through two distinct mechanisms. Firstly, it attracts more firms in the industry, thus increasing aggregate production for a given emission rate. Secondly, it increases the fraction of firms that employ a more polluting technology, thus increasing emissions for a given level of production. Since both mechanisms work towards the same direction, the overall effect is an unambiguous increase in pollution.

5 The Corruption-Pollution Nexus when $t \geq x$

The purpose of this section is to show that our results remain qualitatively identical when the restriction $t < x$ is relaxed. Although we view this as a less realistic case, we present its corresponding implications for reasons of concreteness. Firstly, let us begin with the case where bureaucrats and firms behave honestly. Naturally, the condition $t \geq x$ implies that all potential entrants will choose to adopt the technology with the relatively low emission rate $\underline{e}$. This is because the payment of the environmental tax is always the more costly option, whatever the realised cost of implementing the clean technology. In this case, the restriction in Footnote 7 does not hold anymore. Instead, the equilibrium market entry in the absence of corruption is[11]

$$n^* = \frac{k - m}{\sqrt{\varphi + (x/2)}} - 1. \tag{33}$$

Now let us consider the case where corruption is an equilibrium phenomenon in the sense that bureaucrats are seeking bribes in order to conceal the actual circumstances of firms which are willing to offer them. Although all firms would be willing to adopt the cleaner technology in the absence of corruption, the opportunity offered by corrupt bureaucrats allow some of them to use the costless, more polluting technology while claiming to do otherwise. It is straightforward to verify that the analysis and results summarised in Equations (14)-(26) are the same. The only difference is that the restriction $t < x/\sigma$ is required to make the story non-trivial. If this condition does not hold, then all firms will choose not to pay bribes as adopting the cleaner production technology is a less costly option – a conjecture that is evident from Equations (15) and (18). Hence we can assume that $x < t < x/\sigma$ holds.

The previous discussion reveals that the implication of Lemma 4 still applies, simply because all firms will adopt the clean technology in the absence of corruption, i.e., $\theta^* = 0$, contrary to what happens in the presence of corruption where a fraction $\theta^{**} = \int_{\hat{c}}^{x} f(c_j)dc_j = \frac{x - \sigma t}{2x}$ of firms will employ the high-emission technology and bribe bureaucrats to misreport their true circumstances. In order for Proposition 2 to remain

[11] This result can be easily established once we set $\pi = v - \int_0^x c_j f(c_j)dc_j = v - \frac{x}{2}$ equal to φ.

intact, it is sufficient to show that $n^{**} > n^{*}$ holds as well. Alternatively, it is sufficient to show that

$$\frac{(x+\sigma t)(3x-\sigma t)}{8x} \leq \frac{x}{2} \Rightarrow$$

$$3x^2 + 2x\sigma t - (\sigma t)^2 \leq 4x^2 \Rightarrow$$

$$2x\sigma t - (\sigma t)^2 - x^2 \leq 0\,, \tag{34}$$

holds. Notice that (34) can be written as $-(x-\sigma t)^2$ which is unambiguously negative. Therefore, it is indeed true that $n^{**} > n^{*}$.

6 Conclusion

Existing empirical evidence shows that corruption is among the factors that are responsible for higher pollution. The increased awareness on environmental issues, such as climate change, and the efforts by nations around the world to take collective action in order to address them is indicative of the importance that should be attached to the understanding of the possible mechanisms behind this relation. Such knowledge may facilitate economists and policy makers in their attempts to recognise the conditions that determine the effectiveness of environmental regulations and policies, especially in developing countries where the problem of corruption appears to be more salient and persistent.

The main purpose of our paper was to identify a previously unexplored channel through which the incidence of corruption impinges on total emissions. This mechanism is associated with market entry. Particularly, we have shown the possibility of a self-reinforcing cycle, whereby corruption leads to an increase of the number of (polluting) firms that compete in the market, whereas the same increase in market entry raises the incentives of bureaucrats to engage in corrupt activities. These two-way causal effects lead to multiple equilibria. One of these equilibria is characterised by the presence of corruption and relatively high pollution; the other regime is characterised by the absence of corruption and relatively low pollution. The incidence of corruption impinges on environmental quality through two distinct mechanisms. Firstly, it increases the number of firms that undertake (polluting) production. Secondly, it increases the fraction of firms that employ the technology which releases more emissions per unit of production.

Despite the obvious policy component of our framework, our analysis and discussion are positive rather than normative. Our purpose was to illustrate additional economic and environmental implications that may arise due to the moral hazard issues generated by the implementation of a specific environmental policy. We did not make any attempt to suggest mechanisms that will improve the effectiveness of environmental policy since this is an issue that goes beyond the scope of our current analysis. Nevertheless, issues of mechanism design in the effort to reduce corruption and increase the effectiveness of environmental policy are indubitably important; thus, they certainly represent a worth pursuing avenue for future research.

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