

Three Essays in Green Technology and Environmental Policy



Thesis submitted for the degree of
Doctor of Philosophy at the University of Leicester

by

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March 2016

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Abstract

This thesis comprises three essays on environmental economics and deals with issues such as corruption, emissions leakage and green alliances. Chapter 1 investigates the relationship between corruption and market entry. We show that corruption incentivises firms' entry in the market while an increased number of firms incentivises bureaucrats to be corrupt, in a self-reinforcing manner. Although the applicability of the model can be more general, we focus on the case of environmental regulation and show the positive relationship between corruption and pollution through market entry. In the second chapter, an additional factor which leads to emissions leakage is proposed. In a setting with two countries, when consumers in one country care only about domestic emissions, emissions leakage arises since demand for the good that is produced in that country using a greener technology is shifted abroad where production takes place with the dirtiest technology. Next, I consider the global environmental consciousness scenario i.e., consumers in that country now care about both the domestic and foreign emissions. In this case, foreign pollution is mitigated and leakage is diminished. In the last chapter, I examine green alliances, the partnerships between a firm and an environmental group. In this model, the environmentalists have two options: to either act against the firm which implies shrinking the demand that the firm faces or join forces with it by reducing the cost of implementing a greener technology. The group's decision is affected by an environmental tax set by the government and by extension it impacts firm's choices on output and emission intensity. It is shown that higher taxation makes the conflict scenario more likely to happen, implying that collaboration and a more stringent environmental policy are substitutes. This identifies a previously unexplored, possibly adverse effect of public policy on environmental quality.

*Στους αγαπημένους γονείς
και αδερφό μου*

Acknowledgements

I would like to express my sincere gratitude and appreciation to Dr. Dimitrios Varvarigos for his unwavering support, encouragement and patience over the past four years. The joy and enthusiasm he has for research was motivational for me, even during tough times in the Ph.D. pursuit. I am also extremely grateful to Dr. Piercarlo Zanchettin for giving me the benefit of his advice and knowledge and for accepting to supervise me in the last two years of my PhD as well as Dr. Maria Gil-Moltó for always being kind and willing to assist and guide me during the first two years of my studies.

This thesis would not have been possible without their enthusiastic support. They all encouraged me to think critically and creatively and I appreciate their time and effort. It is due to their guidance and teaching that not only my economics skills have furthered and improved but also I managed to secure a job in academia. I feel very privileged to have worked with them.

I would like to acknowledge the Department of Economics for having me and financing my studies and all the academics for creating a friendly and inspiring environment for research.

I am also thankful to my friends, those in the distance and those I met in the department, for making this PhD such a fun and special journey. Special thanks to my officemates in LG07.

Last but not least, I am indebted to my parents, Areti and Christos, my beloved brother Konstantinos, my aunt Yiota and my uncle Antonis. And, of course, my beloved John who is always there for me. I feel honoured and very fortunate to have them.

Declaration

Chapter 1 entitled “Corruption and market entry” is a joint work with Dr. Dimitrios Varvarigos, University of Leicester. An earlier version of this chapter has been accepted in the 13th Conference on Research on Economic Theory & Econometrics (CRETE) conference at Milos, Greece in July 2013 and it has been published in the 2013 University of Leicester Discussion Paper Series in Economics.

Chapter 2 entitled “Environmental awareness and emissions leakage” has been presented at the 4th Network of Industrial Economists (NIE) Colloquium, 2014 (Nottingham), the Oligo Workshop, 2015 (Madrid) and the Public Economic Theory (PET 15) conference, 2015 (Luxemburg). An earlier version has also been published in the 2014 University of Leicester Discussion Paper Series in Economics.

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Introduction

The improvement of environmental quality is a central topic and a core objective in the climate change debate. It is indicative of its importance that it has been included in several action programmes such as the recent “Horizon 2020”, the biggest EU research and innovation programme with nearly 80 billion euros of funding available from 2014 to 2020. Many scholars have also explored its determinants and proposed as well as evaluated policies that would promote it. This thesis adds to the debate by exploring issues such emissions leakage, corruption and partnerships between firms and environmental groups (EGs) and how these affect environmental quality.

The first chapter sheds light on the conditions that underpin the corruption-market entry nexus. We show the possibility of a self-reinforcing cycle where corruption increases the number of entrants in the industry due to the reduction of the expected operating costs while this larger number of competing firms increases the bureaucrats’ incentives to be corrupt, mainly because a market with more firms offers a larger pool of potential bribe payers, thus increasing the expected benefits of being corrupt. Although the applicability of our model can be more general, we apply the preceding analysis on the case of environmental regulation and identify market entry as the underlying mechanism through which corruption impinges on environmental quality. In particular, the incidence of corruption impacts on total emissions through two channels. Firstly, it increases the number of firms that undertake production. Secondly, it may also increase the fraction of firms that employ the technology which generates more emissions per unit of production. We

also present extensions of the model where we relax various assumptions of the baseline model and we show that the main results hold qualitatively.

The second chapter focuses on the possibility that consumers of different countries display a different degree of environmental awareness. It shows that, in an international duopoly context, if consumers in one country display local environmental awareness (i.e., they care only about domestic emissions), emissions leakage occurs as consumers shift their demand to the good produced abroad, even though the domestic firm tries to compensate for the reduction in its demand by employing a cleaner technology. Aggregate output and pollution are anyway lowered compared to the benchmark setting, where consumers are not environmentally aware at all and all firms choose the dirtiest production technology. Next, I consider the case where consumers in that country care about both the domestic and foreign emissions and I find that in this case the extent of the emissions leakage diminishes and both firms undertake investments to employ cleaner technologies.

In the third chapter, I examine two alternative strategies that an environmental group may choose when interacting with a firm. The first one which is already extensively discussed in the literature is when the group campaigns against the firm and in particular against the negative consequences its production entails. The second one which, to the best of my knowledge, has not been modelled in the literature yet is when the group collaborates with the firm (green alliance) by sharing its know-how in order to reduce the implementation cost of the cleaner technology and provide incentives to the firm to employ it. The idea of presenting the environmentalists having these two options instead of only acting against the firm comes from the fact that the notion of radical environmentalists clashing with firms characterises a classic way of thinking but as time marches forward, this landscape is changing. One of the main results of this chapter suggests that for higher pollution taxation the conflict scenario is more likely to happen, implying that collaboration and a more stringent environmental policy are substitutes. This identifies a formerly unexamined and possibly adverse effect of public policy on environmental quality.

The effect of the pollution tax rate on emission intensity is mitigated since the latter is higher under conflict. Due to the complexity of the problem, I undertake numerical examples to calculate the optimal tax that maximises Social Welfare and I find that the optimal tax rate when conflict is the only option for the environmentalists is higher than in the case where the group can choose to either act against or join forces with the firm.

Chapter 1

Corruption and market entry: the case of environmental technology

1.1 Introduction

According to Transparency International, corruption can be defined as “the abuse of entrusted power for private gain”. It involves the exploitation of power by individuals in both the higher ranks of public administration (*grand* corruption) and in the low- and mid-level public offices (*petty* corruption)¹. By its very nature, corruption can infringe on a country’s social, economic as well as political domains, while its repercussions can be potentially far reaching.

One of the economic aspects whose relation with corruption has received considerable attention is market structure. Bliss and Di Tella (1997) were among the first to offer a formal analysis on the interplay between corruption and entry: assuming that corrupt officials receive bribes in order to issue licence fees that permit firms to compete in a market, they find that corruption affects market entry and that different measures of competition intensity have ambiguous effects on both entry and the magnitude of corruption. The idea that corrupt bureaucrats demand

¹http://www.transparency.org/whoweare/organisation/faqs_on_corruption#defineCorruption.

bribes in exchange for entry licenses is also a feature of subsequent analyses on the issue. Emerson (2006) obtains multiple equilibria where high (low) corruption is associated with low (high) entry. This is because of reinforcing effects where bribes shrink profits, while reduced entry allows bureaucrats to extract a greater surplus from existing competitors. In the model of Amir and Burr (2015), the assumption of pre-existing firms in the market generates additional effects through which the number of new entrants under corruption may be higher than the number corresponding to the second-best. Nevertheless, the total number of competing firms under corruption is lower compared to the market solution without corruption.

The aforementioned theoretical analyses suggest a negative relation between corruption and market entry. However, the existing evidence on this issue is not equally unambiguous. For example, while the empirical investigation of Ades and Di Tella (1999) shows that different measures of competition are inversely related to corruption, the recent study of Dreher and Gassebner (2013) presents evidence that corruption facilitates entry in economies where market activity is significantly regulated. This inconclusiveness is certainly indicative of the need for further investigations that can shed light on the conditions that underpin the corruption-market entry nexus.

This chapter seeks to offer such a theoretical investigation. Our departure from the previously mentioned analyses is threefold. Firstly, rather than assuming that corrupt bureaucrats effectively control market entry, we consider a case where corruption allows firms to circumvent regulations in a manner that reduces their operating costs. Specifically, we envisage a scenario where, in exchange for bribes, corrupt bureaucrats facilitate firms in evading the tax payments associated with the implementation of a specific regulation. Of course, government could ensure that no cheating takes place by imposing an arbitrarily large fine on every firm and/or official caught cheating. However, this argument ignores issues such as limited liability, the possibility of a corrupt bureaucrat who abuses the system (threatens the firm) or, alternatively, harshly punishes someone who makes an honest mistake as well

as the case where the authorities may be more reluctant to find the firm guilty of misreporting where one practical consequence may be fewer penalties imposed (Slemrod, 2015). If anything, this is an empirically relevant case that warrants attention given that tax evasion is an important facet of corruption in the corporate world. Crocker and Slemrod (2005) cite evidence that corporate tax underreporting in the United States amounts to almost \$37.5 billion, while Joulfaian (2009) presents cross-country evidence showing that corporate tax evasion is more pronounced in economies where bribes to tax officials represent a common occurrence. Secondly, in contrast to the models of Bliss and Di Tella (1997), Emerson (2006) and Amir and Burr (2015), in our framework bureaucrats are *potentially corruptible*. In other words, bureaucrats will decide endogenously on whether to take advantage of their position and seek bribes from firms that are willing to engage in tax evasion, or to abstain from such wrongdoing and behave honestly. The third departure is that, following Acemoglu and Verdier (2000), we focus on the case of environmental policy and taxation. This approach is justified by the fact that environmental regulation is an area in which the effect of corruption seems to be particularly pertinent. Indeed, there is ample empirical support for this argument. 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) argues that one of the consequences of corruption is that emissions tend to be significantly underreported. Hubbard (1998) and Oliva (in press) employ empirical analyses to argue that the effectiveness of vehicle emission controls is significantly reduced as a result of corruption and misconduct 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 arguments that are also echoed in the empirical analysis of Burgess *et al.* (2012).

Another argument supporting the importance and relevance of our approach is that the relation between the quality of the natural environment and 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 –in fact, there is unequivocal empirical support for the fact that the overall effect of corruption on pollution is positive (e.g., Welsch, 2004; Cole, 2007). Therefore, the knowledge of possible mechanisms behind this relation can facilitate economists and policy makers in their attempts to recognise the conditions that determine the effectiveness of environmental regulations and policies.

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 environmental 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 tasks of verifying the technology employed by firms and taking the appropriate action, i.e., collecting 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. The characteristics of the model's equilibrium are the following. On the one hand, corruption increases the number of entrants in the market since the opportunity of bribing bureaucrats to avoid the tax burden associated with the use of the costless, but more polluting, technology increases expected profits. The result is rather different to what the existing literature has obtained but it is supported by the empirical evidence of Dreher and Gassebner (2013). In the context of our framework it is also quite intuitive and it stems from the fact that, for tax evasion to be a meaningful option for a firm, the bribe it pays must be less than the amount of the tax evaded. 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 multiple equilibria, as there are parameter configurations for which any of these two regimes represents a possible equilibrium outcome. This result is in line with the previous studies on corruption that examine its variability across regions with essentially the same structural characteristics and show the existence of multiple equilibria. Lui (1986) presents an overlapping-generations model of corruption deterrence where the expected gains from corruption depend upon the number of other people who are expected to be corrupt. In particular, it is assumed that when corruption becomes more prevalent in the economy it is harder to audit a corrupt official effectively. It is shown that this assumption may give rise to several stationary equilibrium levels of corruption and was exploited to explain why sometimes a government may temporarily resort to an extremely severe deterrence policy and why the same deterrence scheme may imply quite different levels of corruption. In his paper, Sarte (2000) explains why bureaucratic corruption is likely to be detrimental to economic development in which rent-seeking bureaucrats restrict the entry of firms into the formal sector of the economy which has a better system of property rights and law enforcement than the informal sector. He shows that when the costs of informality are high, growth is reduced relative to the free-entry case and that because the game is infinitely repeated, there may exist many equilibria. Shi and Temzelides (2004) examine an economy with bureaucracy where the punishment on corruption as the loss of the benefit arising from being part of the bureaucracy is endogenous and they indicate two self-fulfilling equilibria; in one, bureaucrats accept bribes, whereas in the other they do not. Additionally, Blackburn et al. (2006) investigate why the incidence of corruption is so diverse among countries, but also why this diversity appears to be so persistent and argue that the possibility of multiple equilibria arises from the mutual interaction between bureaucratic decision making and aggregate

economic activity. In Emerson’s (2006) paper, multiple equilibria can arise where one equilibrium is characterised by high corruption and low competition, and another is characterised by low corruption and high competition. As discussed earlier and opposite to our results, this is because in his paper bureaucrats control access to a formal market and reduced entry allows bureaucrats to extract a greater surplus from existing competitors. In Verbrugge’s (2006) model, multiplicity of equilibria is explained through the two features of corruption: the strategic complementarity between the level of corruption and the likelihood of an agent to act in a corrupt manner and the localised interactions i.e., officials typically interacting repeatedly with a small group of other officials.

On the whole, there are two distinct channels through which corruption can affect pollution. Firstly, corruption increases the fraction of firms which are expected to adopt the more polluting technology –a direct effect that is corroborated by empirical evidence to which we alluded earlier. Secondly, 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.

At this point it should be noted that although we employ the case of environmental regulation, the applicability of our model can be more general. For instance, the “clean” and “dirty” technologies can be reinterpreted as a firm’s decision to comply or not with a health and safety regulation, whereas the “environmental tax” can be reinterpreted as the penalty for non-compliance. The implications of our model regarding the relation between corruption and market entry would remain intact.

Our main results are robust to extensions that relax various assumptions of our baseline model. In the most significant of these extensions, we postulate that, by receiving bribes from an increasing number of firms, in exchange for facilitating them in evading the payment of the environmental tax, the corrupted bureaucrat increases his exposure, thus becoming more vulnerable to detection by authorities. Despite

the fact that, on the outset, this implies that increased entry would have a negative effect on the expected utility of the corrupted bureaucrat, in addition to the positive one to which we alluded earlier, qualitatively our main results remain intact. The reason is that the bureaucrat mitigates this negative effect by demanding a higher bribe from fewer of the firms he monitors.

Given the above, our model raises awareness to a previously unexplored mechanism that contributes to the understanding of the empirically supported, positive relation between corruption and total emissions. Particularly, one of our contributions is to identify market entry as an important element in the corruption-pollution nexus. In relation to the relevant 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. López and Mitra (2000) consider a government that imposes environmental regulations and a firm that decides how much to bribe the government in order to relax this regulation. They find that the turning point of the environmental Kuznets curve occurs at a level of income that is above the one associated with the social optimum. Damania (2002) examines how corruption affects the optimal design of environmental regulations in a framework where the firm bribes an inspector in order to reduce taxable emissions. Damania *et al.* (2004) expand this framework by assuming that the firm can also lobby in order to induce favourable changes to environmental regulations. They find that political instability increases both types of corruption, i.e., it intensifies both the bribery to inspectors and the incidence of lobbying with the purpose of relaxing environmental regulations. All these analyses focus on the case of a single representative firm and abscond from issues relating to the number of competing firms. Consequently, contrary to what we do in this paper, they analyse neither the repercussions of corruption for market entry nor the effect that entry decisions may have on corruption incentives – in other words, the type of strategic complementarities that may generate equilibrium multiplicity in our framework. The model of Acemoglu and Verdier (2000) examines

emission tax evasion in a framework that allows for occupational choice, given that agents can be employed either as entrepreneurs or public officials. Despite the fact that their set-up has implicit implications for the number of firms that produce output (i.e., how many agents will become entrepreneurs rather than bureaucrats), they argue that corruption increases the size of the bureaucracy, thus reducing the size of the market – a result that is the opposite to the one we find in this paper. Furthermore, they do not have any implications for the strategic complementarities inherent on the nexus between entry decisions and corruption incentives².

The remainder of our analysis is organised as follows. In Section 1.2 we outline the characteristics of the market in which firms produce and supply their products. Section 1.3 analyses the incentives for corruption by both firms and bureaucrats and identifies the interplay between corruption and market entry as well as the repercussions for pollution. It also argues in favour of the wider applicability of our framework. In Section 1.4, we show that our results are robust to various extensions, including the case where inspection of the firm is uncertain. Section 1.5 concludes.

1.2 The market

1.2.1 Demand

Consider a market 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 $\eta(u_i)$. Using p to denote the price of the homogeneous good, it follows that each

²Another 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.

consumer's surplus is

$$s_i = u_i - p. \tag{1.1}$$

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 (1.1), it is straightforward to establish that the consumers who will buy and consume the good are those consumers whose preferences satisfy $u_i \in [p, k]$. Therefore, the fraction of consumers purchasing the good is equal to

$$\int_p^k \eta(u_i) du_i = \frac{k - p}{k}. \tag{1.2}$$

We can use Eq. (1.2) to get the aggregate demand function

$$Q = \frac{k - p}{k} k = k - p, \tag{1.3}$$

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 suppresses 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 (1.3), the inverse demand function can be written as³

$$p = k - Q. \tag{1.4}$$

1.2.2 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 $Q =$

³Equivalently, we could derive the same demand function, without resorting to preference heterogeneity across consumers, by using the linear-quadratic utility function $kQ - (Q^2/2) + \varsigma$, which consumers would maximise subject to the constraint $pQ + \varsigma = y$ (ς captures the quantity of all other goods in the economy while y is consumer income). See Martin (2009) for details.

$\sum_{j=1}^n q_j$. Therefore, we can use Eq. (1.4) to express a firm's variable profit, denoted v_j , according to

$$v_j = \left(k - \sum_{j=1}^n q_j \right) q_j - m q_j, \quad (1.5)$$

where $m > 0$ is the per unit cost of production⁴. 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

$$\frac{\partial v_j}{\partial q_j} = 0 \Leftrightarrow k - \sum_{j=1}^n q_j - q_j^* - m = 0. \quad (1.6)$$

Combining the market clearing condition $Q = \sum_{j=1}^n q_j$ with (1.4) and (1.6), it follows that the equilibrium is symmetric; that is, $q_j^* = q^* \forall j$. Using (1.6), we get

$$q^* = \frac{k - m}{1 + n}. \quad (1.7)$$

Given $Q = nq^*$, we can substitute (1.7) in (1.4) to get

$$p = \frac{k + nm}{1 + n}. \quad (1.8)$$

The variable profit of a firm equals $v = (p - m)q^*$. Substituting Eq. (1.7) and (1.8), we get

$$v = \left(\frac{k - m}{1 + n} \right)^2. \quad (1.9)$$

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 revenue and, therefore, variable profit.

⁴We assume $m < k$ so that each firm produces a strictly positive quantity of output (see Eq. 1.7).

1.3 Corruption Incentives, Entry, and the Environment

There are two technologies available for each firm to choose⁵. The relatively dirty technology emits $\bar{e} > 0$ pollutants per unit of production and can be adopted at zero cost. However, firms that employ this technology are liable to an environmental tax/penalty, equal to $t > 0$. The relatively clean technology emits $\underline{e} < \bar{e}$ 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 compete in the industry⁶. 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 density function $f(c_j)$.

As it is evident from the preceding description, the emission tax in this context is a lump-sum, rather than proportional to emissions. The reason for this assumption is that, had the emission tax being proportional to output, the ability to evade taxes would impinge on both the technology choice and the quantity produced by the firm. In such a setting, the amount of tax paid would automatically convey information on whether the firm engaged in corrupt activities or not – after all, it would be straightforward for the authorities to calculate the optimal quantity of output produced under each of the two technologies⁷. Our setting does not allow for such a possibility; instead, the fixed emission tax scheme renders the evading firm’s claim convincing on the outset, albeit an ultimately false one. In any case, our

⁵Other analyses of environmental regulation and emission reporting have employed the assumption of a binary technology choice. See, for example, Malik (1993) and Acemoglu and Verdier (2000).

⁶Uncertainty on costs or factors such as productivity and the ability factor are reasons why the adoption cost is realised after the firm decides to enter and operate in the industry.

⁷Under certain context, it could be possible that the “dirty” firms engaged in bribing to avoid the tax try to mimic the relatively clean firms so that it would not be immediately apparent whether a firm has installed the clean technology. However, the examination of this case goes beyond the scope of this analysis and represents a fruitful venue for future research.

scenario is not alien to real-world circumstances surrounding emission taxes. As a matter of fact, there are actual examples that are consistent with this approach. In a report published by the Environmental Protection Agency, the section devoted to the California Air Toxics “Hot Spots” Information and Assessment Act clearly states that *“the fee structure, which is used in 12 of California’s 34 air pollution control districts, is no longer based on tonnage of emissions [...] Facilities with fewer than 50 weighted pounds pay nothing, while facilities with weighted emissions between 50 and 1,000 pounds pay a flat fee of \$125”* (EPA 2001, p. 40).

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 check the technology adopted by each firm and therefore decide on whether a tax should be collected or not. We assume that the government hires δ bureaucrats, where δ is a continuous variable and $\delta < n$, and it 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. This assumption is relaxed in Section 1.4.2 where we assume that only a number of firms is inspected and we show that our results hold qualitatively.

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 market. This fixed cost is equal to $\phi > 0$. During the second stage, each firm chooses which technology to employ, a choice that is monitored and verified by a bureaucrat. 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.

Now, let us consider a firm that has decided to compete in the market⁸. During

⁸Examples of a polluting industry with many firms where entry is important, as in this model, include the steel, the mining and the energy industries.

the second stage, the firm will adopt the clean technology as long as $v - c_j \geq v - t$ ⁹ $\Leftrightarrow t \geq c_j$. Given that $t < x$ holds, a firm j will be willing to use the clean technology, as long as

$$c_j < t. \quad (1.10)$$

Given (1.10), 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 \bar{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

$$\pi_j = v - \int_0^t c_j f(c_j) dc_j - t \int_t^x f(c_j) dc_j = v - \frac{t^2}{2x} - \frac{t(x-t)}{x} = v - t + \frac{t^2}{2x} = v - \mu \equiv \pi, \quad (1.11)$$

where

$$\mu = \frac{t(2x-t)}{2x}. \quad (1.12)$$

Potential entrants will wish to pay the fixed cost of entry and compete in the market as long as $\pi \geq \phi$. 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 $\pi = \phi$. Using (1.9) and (1.11), it follows that the equilibrium number of firms can be calculated as

$$n^* = \frac{k-m}{\sqrt{\phi + \mu}} - 1. \quad (1.13)$$

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. Formally, this may happen if $(k-m)/\sqrt{\phi + (x/2)} < 1$. This outcome can be possible since firms make their entry decisions based on an expectation for

⁹The possibility of a firm entering the market and producing zero output is ruled out by assuming $v > t$.

c_j (recall that the actual cost is realised after entry takes place). Our current assumption seems to describe the more realistic scenario. The alternative assumption would imply that the government can potentially 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 1.4.1 we relax this restriction and show that our results remain qualitatively intact.

The result in Eq. (1.13) gives the equilibrium number¹⁰ 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 inspects. 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 practice 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, augmented by a proportional penalty rate, say $r > 1$, to the payment of the evaded tax.

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 $\zeta \in (0, 1)$ to be the probability that the authorities will eventually detect the firm that has evaded the

¹⁰We treat the number of firms n as a discrete variable, so we assume that n derived from the zero profit condition is rounded to the closest integer.

tax. In order for tax evasion to be a meaningful choice, henceforth we assume that $\zeta < 1/r$. We also use the composite term $\sigma \equiv \zeta r$ ($0 < \sigma < 1$), to save on notation. The expected profit for the firm is

$$v - (b + \sigma t),^{11} \tag{1.14}$$

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

$$c_j < b + \sigma t \equiv \hat{c} \tag{1.15}$$

Given (1.15), 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 expected number of firms willing to engage in a fraudulent collusion with a bureaucrat can be found from

$$n \int_{\hat{c}}^x f(c_j) dc_j = n \frac{x - \hat{c}}{x} = n \frac{x - (b + \sigma t)}{x}. \tag{1.16}$$

As it is evident from (1.16), a higher bribe will reduce the expected 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 the adoption of the more polluting technology and agrees to the corrupt official's demands 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.

¹¹Similarly to the previous case without corruption, the possibility of a firm entering the industry and producing zero output is ruled out by assuming $v > b^* + \sigma t$. Using (1.18), this implies $v > \frac{x + \sigma t}{2}$.

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, we use $\beta \in (0, 1)$ to denote the probability that a corrupted bureaucrat will be detected and punished for his nefarious activities. With regard to apprehended bureaucrats, the penalty for their misconduct is that they are dismissed without pay and they also lose all their ill-gotten gains. We shall also assume that the corrupt bureaucrat faces a fixed utility cost $\Lambda > 0$. This cost may capture various elements such as moral concerns, the anxiety associated with the fear of possible detection and punishment etc.¹² Given this discussion, the expected utility λ^C of a corrupted official is

$$\lambda^C(b; n) = (1 - \beta) \left[\omega + \frac{x - (b + \sigma t)}{x} \frac{n}{\delta} b \right] - \Lambda. \quad (1.17)$$

Naturally, the bureaucrat will demand a bribe that maximises his expected utility¹³. 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

¹²This is to ensure that taking bribes is not strictly dominant for the bureaucrats but may depend on the numbers of firms as it will be shown in Lemma 1.2.

¹³In this context, the bureaucrat has all the bargaining power in choosing the bribe he will demand in order to conceal the true circumstances of firms that wish to evade their tax obligation. This implies that he makes a take-it-or-leave-it bribe demand to all firms. This is not in conflict with the literature. Bliss and Di Tella (1997) assume that the bureaucrat makes a take-it-or-leave-it offer to the firms and Amir and Burr (2015) assume that the bureaucrat charges a fixed endogenous share of anticipated profits.

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 $b^* = \operatorname{argmax} \lambda^c(b; n)$. We can use (1.17) and set $\frac{\partial \lambda^c(b; n)}{\partial b} = 0$ to obtain

$$b^* = \frac{x - \sigma t}{2}. \quad (1.18)$$

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

Lemma 1.1. *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 Eq. (1.18), this condition is equivalent to

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

which holds by assumption. □

Let us discuss the characteristics of the result in (1.18). 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 firm¹⁴. To clarify this point even further, recall that, due to the discrete nature of the environmental tax, a firm that successfully gets away when conspiring in order to falsely represent its actual technology choice, avoids the tax liability altogether. The only way through which the tax impinges on the firm's profitability and choice of technology *directly* is as an expected cost in the case of detection. Nevertheless, this is not inconsistent with the notion that the presence of the tax is what ultimately creates the conditions for the emergence of corruption. This idea is inherent in each firm's participation condition which implies that the chosen bribe is $\min\{b^*, (1-\sigma)t\}$. For example, in the extreme case where $t = 0$, we have $(1 - \sigma)t = 0 < b^*$ where b^* is the result in Eq. (1.18). Thus, none of the producers would pay a bribe, simply because none of them would have the incentive to do so; all of them would just employ the dirty technology¹⁵.

Now, let us substitute (1.18) in (1.17) in order to write the expected utility of a

¹⁴Assuming 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 (1.10) and (1.15) 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 1.1.

¹⁵As mentioned earlier, the corrupt bureaucrat sets the same take-it-or-leave-it bribe to all firms. An alternative scenario could be the setting where the official is able to discriminate between firms i.e., setting a lower (higher) bribe for firms with lower (higher) costs of adopting the clean technology. However, this may not be feasible if the realisation of c_j cannot be observed by the official (private information) as it is assumed in our model. Also, it may be too costly for the bureaucrats trying to distinguish the firms' circumstances which in turn also creates the incentive for the firm to misrepresent its true circumstances.

corrupted official as

$$\lambda^c(n) = (1 - \beta) \left[\omega + \frac{(x - \sigma t)^2 n}{4x \delta} \right] - \Lambda. \quad (1.19)$$

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

$$\lambda^H = \omega, \quad (1.20)$$

i.e., he will not accept bribes from firms and his income will be composed only of his salary. Here, the salary paid to the bureaucrat is not related to the number of firms he inspects. However, this assumption is relaxed in section 1.4.3 and we show that our results hold qualitatively. 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 (1.19) and (1.20), a process that allows us to infer

Lemma 1.2. *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 corrupt.*

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

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

$$\hat{n} = \frac{4x\delta(\beta\omega + \Lambda)}{(x - \sigma t)^2(1 - \beta)} \quad (1.21)$$

Hence, assuming $4x\delta(\beta\omega + \Lambda) > (x - \sigma t)^2(1 - \beta)$ to ensure $\hat{n} > 1$, the result of Lemma 1.1 follows from the fact that $\frac{\partial \lambda^C(n)}{\partial n} > 0$ and $\frac{\partial \lambda^H}{\partial n} = 0$ according to (1.19) and (1.20) respectively. \square

Among other factors, the number of firms that compete in the market 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 which, in this setup, is independent of the number of firms audited. 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

$$\pi_j = v - \int_0^{\hat{c}} c_j f(c_j) dc_j - (b + \sigma t) \int_{\hat{c}}^x f(c_j) dc_j = v - \frac{\hat{c}^2}{2x} - \frac{(b + \sigma t)(x - \hat{c})}{x}. \quad (1.22)$$

Substitution of (1.15) in (1.22) yields

$$\pi_j = v - \frac{(b + \sigma t)^2}{2x} - (b + \sigma t) + \frac{(b + \sigma t)^2}{x} = v - (b + \sigma t) + \frac{(b + \sigma t)^2}{2x}, \quad (1.23)$$

to which we can substitute (1.18) and derive

$$\pi_j = v - \frac{x + \sigma t}{2} + \frac{(x + \sigma t)^2}{8x} = v - \frac{x + \sigma t}{2} \left(1 - \frac{x + \sigma t}{4x}\right) = v - \gamma \equiv \pi, \quad (1.24)$$

where

$$\gamma = \frac{(x + \sigma t)(3x - \sigma t)}{8x}. \quad (1.25)$$

Taking account of the fixed cost of entry, firms will have the incentive to compete in the market as long as $\pi \geq \phi$ holds. Once more, the equilibrium number of firms will be determined by $\pi = \phi$. Using (1.9) and (1.25), we can calculate equilibrium entry according to

$$n^{**} = \frac{k - m}{\sqrt{\phi + \gamma}} - 1. \quad (1.26)$$

The result in Eq. (1.26) is analogous to Eq. (1.13), the only difference being that now entry has been determined in an environment where bureaucrats are 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 1.3. *Equilibrium entry is higher in the presence of corruption among bureaucrats. That is, $n^{**} > n^*$.*

Proof. Inspection of (1.13) and (1.26) reveals that $n^{**} > n^*$ holds, as long as $\gamma < \mu$. Indeed, we can use (1.12) and (1.25) to investigate the conditions for which

$$\begin{aligned} \frac{(x + \sigma t)(3x - \sigma t)}{8x} &\leq \frac{t(2x - t)}{2x} \Rightarrow \\ 3x^2 + 2x\sigma t - (\sigma t)^2 &\leq 8xt - 4t^2 \Rightarrow \\ 3x^2 - 2xt(4 - \sigma) + t^2(4 - \sigma^2) &= L(t) \leq 0, \end{aligned} \quad (1.27)$$

holds. Taking the first and second derivatives of (1.27) 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 1.1, the minimum possible tax satisfies $t = \frac{x}{2 - \sigma}$. Substituting this in (1.27) yields

$$x^2 \left[3 - \frac{2(4 - \sigma)}{2 - \sigma} + \frac{4 - \sigma^2}{(2 - \sigma)^2} \right] = \frac{x^2}{(2 - \sigma)^2} [3(2 - \sigma)^2 - 2(4 - \sigma)(2 - \sigma) + 4 - \sigma^2] = 0. \quad (1.28)$$

Despite the fact that the derivative $L'(t)$ cannot be signed with certainty, the positive second derivative together with (1.28) imply that, as long as (1.27) holds for the maximum possible tax (that is $t = x$), then it must hold for any $t \in (\frac{x}{2 - \sigma}, x)$. This is because $L(t)$ is U-shaped, thus it admits its highest possible values at the boundaries of the domain $t \in (\frac{x}{2 - \sigma}, x)$. Substituting $t = x$ in (1.27) we get

$$\begin{aligned} 3x^2 - 2x^2(4 - \sigma) + x^2(4 - \sigma^2) &\Rightarrow \\ x^2(-1 + 2\sigma - \sigma^2) &\Rightarrow \end{aligned}$$

$$-x^2(\sigma - 1)^2 < 0. \quad (1.29)$$

The preceding analysis shows that the expression in (1.27) holds as a strict inequality, thus completing the proof of the proposition. \square

The underlying intuition behind Lemma 1.3 is simple. Bureaucrats demand a bribe that will deter some firms from the adoption 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 operating costs. As a result, the expected total profit increases, thus enticing more firms in the market.

As it is evident from Lemmas 1.1 and 1.2, the interplay between corruption and market entry is indicative of strategic complementarities on the decisions made by bureaucrats and firms. The equilibrium implications of such complementarities are formally presented in

Proposition 1.1. *The following summarises all the possible equilibria in terms of corruption and entry:*

- i. For $n^{**} < \hat{n}$, none of the bureaucrats is corrupt and equilibrium entry is characterised by n^* ;*
- ii. For $n^* > \hat{n}$, all bureaucrats are corrupt and equilibrium entry is characterised by n^{**} ;*
- iii. For $n^* < \hat{n} < n^{**}$ both cases where either none of the bureaucrats is corrupt and the number of firms is n^* , or all bureaucrats are corrupt and the number of firms is n^{**} , are possible equilibria.*

Proof. Consider $n^{**} < \hat{n}$. Given Lemmas 1.2 and 1.3, 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 (1.13), 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 $n^* > \hat{n}$. In this case, we

can allude to Lemmas 1.2 and 1.3 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 Eq. (1.26). 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 $n^* < \hat{n} < n^{**}$ 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. \square

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 while using the 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 for 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. Multiple equilibria emerge 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.

1.3.1 A Reinterpretation of the Model

For the reasons that were outlined in the Introduction, we use the case of environmental regulation and policy as a specific and highly relevant example on the joint determination of corruption and market entry. Nevertheless, the applicability of our framework can be more general. To see this, let us discuss a reinterpretation of the model for which our results would still apply.

Consider the case where the firms decide whether to comply with a health and safety regulation, introduced by the government as a means of mitigating the adverse effects (taking the form of health problems, work-related accidents, injuries etc.) that result from inadequate health and safety standards. Taking the decision to comply implies a (random) fixed cost c_j which has the same properties as with the preceding analysis. Failure to comply entails a penalty t . Bureaucrats, who have the task of inspecting firms and, in principle, imposing and collecting the penalty from those that do not comply to the health and safety standards, receive a salary ω for their services. However, in exchange for a bribe, they may fabricate the actual circumstances of a firm that does not abide by the health and safety regulation. Firms that are revealed as having tried to mislead authorities, something that happens with probability ζ , are required to pay t , augmented by a multiplicative factor r , so that $\sigma = \zeta r$; bureaucrats who are revealed as having engaged in such misconduct, something that happens with probability β , are dismissed without pay and forego all their ill-gotten gains.

As it is evident from this reinterpretation of the model, its solution and its equilibrium characteristics remain identical to the ones that have been presented before. In other words, the interplay between market entry and corruption, and the corresponding outcomes in Lemmas 1.1 to 1.3 and Proposition 1.1, will remain intact. Therefore, our results have a wider relevance for issues pertaining to the corruption-market entry nexus in regulated industries.

1.3.2 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 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 number of those competitors that are expected to opt for the adoption of the less polluting production process. The implications from the former effect were presented and discussed in Proposition 1.1. Next, we delve into the implications of corruption for technology choice. Let us denote the fraction of firms expected to choose the relatively dirty technology by θ , meaning that $1 - \theta$ is the fraction of firms expected to adopt the less polluting technology. We begin with the case where there is no corruption among bureaucrats, for which we can use (1.10) to obtain these fractions as

$$\theta^* = \int_t^x f(c_j)dc_j = \frac{x-t}{x} \text{ and } 1 - \theta^* = \int_0^t f(c_j)dc_j = \frac{t}{x}. \quad (1.30)$$

If we use (1.15) and (1.18), we can derive the corresponding shares in the scenario where bureaucrats are corrupt. That is,

$$\theta^{**} = \int_{\hat{c}}^x f(c_j)dc_j = \frac{x - \sigma t}{2x} \text{ and } 1 - \theta^{**} = \int_0^{\hat{c}} f(c_j)dc_j = \frac{x + \sigma t}{2x}. \quad (1.31)$$

These results allow us to derive

Lemma 1.4. *Corruption reduces the expected fraction of competing firms that adopt the less polluting technology, i.e., $\theta^{**} > \theta^*$.*

Proof. Using (1.30) and (1.31), it can be easily checked that $\theta^{**} > \theta^*$ holds, as long as $t > \frac{x}{2-\sigma}$. This condition applies by virtue of Lemma 1.1. \square

Denote expected 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, the expected value of pollutant emissions is

$$S = \theta nq\bar{e} + (1 - \theta)nq\underline{e} = Q[\theta\bar{e} + (1 - \theta)\underline{e}], \quad (1.32)$$

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

Proposition 1.2. *Corruption is associated with greater pollution on average.*

Proof. We can use Eq. (1.7) 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 (1.32) to establish that $\frac{\partial S}{\partial Q} > 0$ and $\frac{\partial S}{\partial \theta} = Q(\bar{e} - \underline{e}) > 0$. Thus, we can allude to the results of Lemmas 1.3 and 1.4 in order to establish that corruption leads to higher pollution. \square

Corruption is expected to increase pollution through two distinct mechanisms. Firstly, it attracts more firms in the market, thus increasing aggregate production for a given emission intensity. Secondly, it makes it more likely that a higher fraction of firms will 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 of pollution.

1.4 Extensions

In order to check the robustness of our results, in this section we present various extensions – each one relaxing assumptions of our baseline model.

1.4.1 The Case where $t \geq x$

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 completeness. 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, market entry in the absence of corruption is¹⁶

$$n^* = \frac{k - m}{\sqrt{\phi + (x/2)}} - 1. \quad (1.33)$$

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 Eq. (1.14)-(1.26) are the same. The only difference is that the restriction $t < \frac{x}{\sigma}$ 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 Eq. (1.15) and (1.18). Hence we can assume that $x < t < \frac{x}{\sigma}$ holds.

The previous discussion reveals that the implication of Lemma 1.4 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 are expected to employ the high-emission technology and bribe bureaucrats to misreport their true circumstances. In order

¹⁶This 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 .

for Proposition 1.2 to remain intact, it is sufficient to show that $n^{**} > n^*$ holds too. Alternatively, it is sufficient to show that

$$\begin{aligned} \frac{(x + \sigma t)(3x - \sigma t)}{8x} &\leq \frac{x}{2} \Rightarrow \\ 3x^2 + 2x\sigma t - (\sigma t)^2 &\leq 4x^2 \Rightarrow \\ 2x\sigma t - (\sigma t)^2 - x^2 &\leq 0, \end{aligned} \tag{1.34}$$

holds. Notice that (1.34) can be written as $-(x - \sigma t)^2$ which is unambiguously negative. Therefore, it is indeed true that $n^{**} > n^*$.

1.4.2 The Case where Inspection is Uncertain

In our baseline model, all firms face bureaucrats who will verify their tax obligation and collect taxes. Now, let us assume that each bureaucrat can monitor at most $d\frac{n}{\delta}$ firms, where $d \in (0, 1)$. Given that there are δ bureaucrats, this means that the number of firms that will have their tax liability examined by a bureaucrat is dn . In other words, d is also the probability that the firm will be inspected by a bureaucrat.

In the absence of corruption, the firm will adopt the clean technology as long as $v - c_j \geq v - dt \Rightarrow dt \geq c_j$. Using this, we can solve the problem and find that equilibrium entry is given by Eq. (1.13), the only difference being that the composite term μ is now equal to $\frac{dt(2x-dt)}{2x}$. In the presence of corruption, a firm will be willing to adopt the clean technology as long as $v - c_j \geq v - d(b + \sigma t) \Rightarrow d(b + \sigma t) \geq c_j$, meaning that the bribe will be chosen to maximise the bureaucrat's expected utility $\lambda^C(b; n) = (1 - \beta) \left[\omega + \frac{x-d(b+\sigma t)}{x} d\frac{n}{\delta} b \right] - \Lambda$. This leads to the optimal bribe $b^* = \frac{x-d\sigma t}{2d}$, a result that can be substituted back to $\lambda^C(\cdot)$ to obtain $\lambda^C(\cdot) = (1 - \beta) \left[\omega + \frac{(x-d\sigma t)^2}{4x} \frac{n}{\delta} \right] - \Lambda$. Equating with $\lambda^H = \omega$ allows us to derive the expression \hat{n} which is analogous to the one in Eq. (1.21). In this case, it is straightforward to establish that $\hat{n} = \frac{4x\delta(\beta\omega + \Lambda)}{(x-d\sigma t)^2(1-\beta)}$. Furthermore, after some straightforward analysis, the zero profit condition leads to the equilibrium entry given in (1.26), the only difference being that the composite

term γ now equals $\gamma = \frac{(x+\sigma dt)(3x-\sigma dt)}{8x}$.

The preceding discussion reveals that the presence of an inspection probability d just adds a scale factor to our previous results. Specifically, it is evident that, in terms of the solutions for n^* , n^{**} and \hat{n} , the results are *qualitatively* identical. The only difference arises from the fact that the composite term dt replaces t in the original results. Hence, the qualitative implications from Lemmas 1.3 and 1.4 and Propositions 1.1 and 1.2 remain unaffected.

Of course, the previous implication holds true when d is constant. One could argue that an alternative scenario involves a situation where d varies with the number of firms, so that the greater this number, then the lower the probability that a firm will be inspected. Formally, this implies $d'(n) < 0$. Such a scenario would actually strengthen the effect of n on a bureaucrat's incentive to be corrupt, as it is straightforward to show after taking the derivative of $\lambda^C(\cdot) = (1 - \beta) \left[\omega + \frac{(x-d(n)\sigma t)^2 n}{4x\delta} \right] - \Lambda$ with respect to n . This is because a lower probability of inspection reduces the expected fraction of firms that will opt for the choice of the less polluting technology, thus inducing the bureaucrat to optimally demand a higher bribe. Note however that a decline in d reduces the *expected* cost of a firm prior to entry, because it lowers the probability that the firm will need to bribe the official who inspects it, in the case where it opts for adopting the more polluting technology. This generates an effect that counteracts the competition effect of n on the zero profit condition, given that $\frac{\partial \mu}{\partial d} > 0$, $\frac{\partial \gamma}{\partial d} > 0$ and $d'(n) < 0$. This outcome undermines the stability of the equilibrium for n derived from the zero profit condition, since it is well known that a meaningful solution for entry requires that any equilibrium, say \tilde{n} , derived from $\pi(\tilde{n}) = \phi$ must lie on the downward sloping part of $\pi(n)$. In that case, one would need to impose specific restrictions to guarantee that $\frac{\partial \pi}{\partial n} < 0$ when evaluated at $n = \tilde{n}$. As long as this is the case, entry would be higher under the corruption regime; hence, the original results would remain qualitatively identical.

1.4.3 The Case where Bureaucratic Salaries are Increasing in the Number of Inspected Firms

So far, our model has employed the assumption that the salaries paid to bureaucrats are not related to the number of firms they inspect. Here we are relaxing this assumption and consider a scenario where $\omega = \omega\left(\frac{n}{\delta}\right)$ such that $\omega' > 0$. We specify $\omega\left(\frac{n}{\delta}\right) = w\left(\frac{n}{\delta}\right)^g$, where $w > 0$ and $g \in (0, 1)$. To minimise on notation and analytical complication, in this case we normalise $\Lambda = 0$.

Using Eq. (1.19) and (1.20), let us define $\tilde{\lambda} = \lambda^C - \lambda^H$, i.e.,

$$\tilde{\lambda} = (1 - \beta) \frac{(x - \sigma t)^2 n}{4x \delta} - \beta w \left(\frac{n}{\delta}\right)^g.$$

From this, we can see that $\frac{\partial \tilde{\lambda}}{\partial n} = (1 - \beta) \frac{(x - \sigma t)^2}{4x \delta} - \frac{g \beta w n^{g-1}}{\delta^g}$ and $\frac{\partial^2 \tilde{\lambda}}{\partial n^2} = -\frac{(g-1)g \beta w n^{g-2}}{\delta^g} > 0$. Thus there exists $\check{n} = \left[\frac{g 4x \beta w \delta^{1-g}}{(1-\beta)(x-\sigma t)^2} \right]^{\left(\frac{1}{1-g}\right)}$ such that

$$\frac{\partial \tilde{\lambda}}{\partial n} \begin{cases} < 0 & \text{if } n < \check{n} \\ > 0 & \text{if } n > \check{n}. \end{cases}$$

Assuming that $(1 - \beta)(x - \sigma t)^2 < 4x \beta w \delta^{1-g}$ holds, it follows that there exists $\hat{n} = \left[\frac{4x \beta w \delta^{1-g}}{(1-\beta)(x-\sigma t)^2} \right]^{\left(\frac{1}{1-g}\right)}$ (where $\hat{n} > 1$ and $\hat{n} > \check{n}$) such that $\tilde{\lambda} = 0$. Since $\frac{\partial \tilde{\lambda}}{\partial n} > 0$ when evaluated at $n = \hat{n}$, we conclude that

$$\tilde{\lambda} \begin{cases} < 0 & \text{if } n < \hat{n} \\ > 0 & \text{if } n > \hat{n}. \end{cases}$$

The above result proves that Lemma 1.2, and therefore all the results we presented in Section 1.3, can survive qualitatively in a framework where bureaucratic salaries are increasing in n .

1.5 Conclusion

Recent empirical evidence shows that corruption may facilitate market entry by facilitating firms in circumventing regulations that inflate their expected operating costs. At the same time, existing evidence shows unequivocally that corruption is among the factors that are responsible for higher pollution. By combining these two (seemingly unrelated) strands of literature, our contribution in this paper was twofold. Firstly, by deviating from the existing literature and assuming that corrupt bureaucrats facilitate tax evasion, rather than “regulating” market entry directly, we have shown the possibility of a self-reinforcing cycle, whereby corruption leads to an increase of the number of 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 which is an interesting implication of our framework. When this happens, the equilibrium outcomes are solely due to the self-fulfilling nature of corruption incentives and entry decisions. In other words, economies that are identical in every respect may experience drastically different circumstances regarding corruption and market entry. Using the aforementioned ideas, our second contribution was to identify a previously unexplored channel through which the incidence of corruption impinges on pollution.

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 policy. Obviously, one can think of various policy implications from an analysis such as ours. To see this, recall that corruption appears to have two conflicting effects on welfare. The negative one is associated with the increase in pollutant emissions; the positive one is related to the outcome concerning increased market entry (which naturally leads to increased consumer surplus). Do these effects imply an “optimal” degree of corruption? What should be the response of policy makers to this trade-off? Our view is that a rigorous

analysis of these issues requires a framework that takes account of the resource constraints that authorities face while implementing their policies. For example, once we identify such constraints we can detect another channel through which corruption impinges negatively on welfare, i.e., the fact that reduced tax revenues may lead to a cut on the provision of utility enhancing public goods and services. This additional effect would increase even further the government's incentive (in terms of social welfare maximisation) in striving to reduce the incidence of corruption.

But how can this be achieved? Our corresponding results are straightforward in this respect. Particularly, one can see that corruption incentives (which may be mutual across bureaucrats and tax evading firms) could be reduced if either more resources are devoted towards the detection of actual cases of evasion or if the government offers high enough bureaucratic salaries. Once more, however, such implications direct us back to the issue of the government's budget constraint. While it may appear easy to argue that certain actions can reduce the incidence of corruption, a pertinent issue is whether the available resources are sufficient to finance and support the extent of actions necessary to achieve this, and (even if this is possible) at what cost in terms of the cut in other utility enhancing public goods. Furthermore, the point of high bureaucratic salaries brings forth the question of possible talent misallocation (see Acemoglu and Verdier, 2000) and the inefficiencies that this may entail.

In short, while all the aforementioned ideas are indubitably important, their proper analysis deserves frameworks that account explicitly for such issues as public budget constraints, provision of public goods and services, occupational choice etc. –issues that go beyond the scope of our current analysis whose purpose was to focus and raise awareness on the characteristics of the corruption-market entry nexus and the corresponding repercussions for pollution. Nevertheless, all these issues certainly represent a fruitful and worth pursuing avenue for future research.

Chapter 2

Environmental awareness and emissions leakage

2.1 Introduction

It is widely acknowledged that pollution has no geographical boundaries and that several environmental problems have an international dimension since their consequences cannot be restricted to the origin country. In recent years, this transboundary nature of pollution is a common phenomenon especially in Asia where pollution (chemical smog and sulphur) from China is causing serious environmental problems in Japan, South Korea and other neighbouring countries. Clearly, environmental degradation in one country can spread to another, demonstrating that the protection of the global environment is the responsibility of all nations.

Additionally, the emissions leakage phenomenon namely the increase of one region's emissions as a direct result of a decrease in another region's emissions due to a cap or limit (for example more stringent regulations) has drawn a lot of attention and has sparked debate among countries and authorities. Most of the leakage occurs in China, India, and the growing Asian economies; it is found that about 1/4 of China's CO₂ emissions are produced during the manufacture of its exports (Yunfeng

and Laike, 2010). Therefore, political concerns about leakage in the fight to mitigate pollution have been addressed in both Europe and the United States.

However, the absence of an international authority to enforce environmental policies, the need for international collaborative action (Benchekroun and Chaudhuri, 2014) and free riding increase the inefficiency of environmental regulations as well as entail market failures. Alongside, emissions which are embodied in international trade meaning the flow of emissions emitted through one country's production to satisfy another country's consumption hamper the examination of who is responsible for these emissions (Wiedmann, 2009) and reduce the effectiveness of global climate policies such as the Kyoto Protocol. Mainly China and other developing countries export more embedded emissions than they import or they consume domestically (Pan *et al.*, 2008). Thus, unilateral efforts to regulate emissions are likely to create leakage and, often, relocation of the polluting industry.

The literature so far has examined not only various environmental policies such as the Kyoto Protocol (Aichele and Felbermayr, 2012) and the Copenhagen 2020 (Böhringer *et al.*, 2014) but also the asymmetric efforts by nations in order to mitigate pollution. The latter are usually in the form of constrained products against unconstrained ones i.e., increased prices for the domestic producers usually due to higher pollution taxes unaccompanied by an increase in import tariffs (Conconi, 2003).

In this chapter, I propose an additional factor that can cause leakage. In an international trade context, increased environmental awareness of only domestic pollution in one country urges consumers of that country to substitute the consumption of the domestic good with the consumption of the foreign good to reduce emissions in their own country. This, as we will see, increases the demand for the foreign good which is produced employing a "dirtier" technology since the foreign firm which produces that good has no incentives to adopt a "cleaner" technology. Thus, having consumers in one country who care only about local pollution, in a setting with two regions for simplicity, leads to the increase of the foreign emissions

and leakage¹.

Indeed, the issue of leakage is ubiquitous and most empirical studies show that the carbon leakage rate can also result from a policy of the size of the Kyoto Protocol and is in the range 5% to 25%. However, there are other studies revealing an even greater scope of the problem, especially for the energy-intensive industry which seems to be the most affected one. For instance, according to Babiker's paper (2005), when energy intensive products are modelled as Heckscher-Ohlin goods, the global carbon leakage rate is found to be even higher and range between 50% and 130%, which implies that a policy to limit carbon emissions in the OECD has the adverse effect of increasing global emissions. Although there are significant differences in the literature on emissions leakage since each empirical paper adopts different assumptions about demand and supply elasticities as well as the actual emission spillovers, what these studies highlight is the significance of the problem and the need to be addressed in the policy making process.

So far, there has been a lot of debate on how to combat emissions leakage and the most prominent policies have been the imposition of import taxes, border adjustments and border rebate for exports among others. Many studies (Altemeyer-Bartscher *et al.*, 2010; Elliott *et al.*, 2010; Fisher and Fox, 2012; Holland, 2012; Monjon and Quirion, 2011) have well discussed and evaluated these practices based on their effectiveness, however, they all agree that none is always preferred for mitigating emissions or leakage since their effectiveness is not straightforward but depends on many parameters and conditions such as the policy objective, the relative emissions rates along with their different measures (Ghosh *et al.*, 2012) and data availability. Additionally, the transboundary nature of pollution may indicate that one solution could be lying in consumers' preferences. Thus, this chapter, apart from showing that local environmental consciousness in one country can be another reason for leakage, examines also whether informing domestic consumers about the

¹The literature on green/environmentally aware consumers is extensive; see Bansal and Ganghopadhyay (2003), Chander and Muthukrishnan (2015), Moraga-Gonzalez and Padron-Fumero (2002), Perino (2015) and Teisl *et al.* (2002) amongst others.

negative effects their consumption choices have on the foreign country, so that now they care about both local and global pollution, can tackle leakage.

Having consumers from different countries with various cultures and incentives who have different levels of environmental consciousness is not an unrealistic assumption. Thus, I include in the model the case of having environmental aware consumers for the domestic pollution in one country (local environmental awareness) and consumption oriented consumers in the other country. This separation is not new in the existing literature of environmental economics (Zagonari, 1998). It is also supported by other studies such as the one by Schumacher (2015) whose main finding is that for low wealth levels, society is unable to free resources for environmental culture. Also, a recent survey by the European Lifestyles Of Health And Sustainability (LOHAS) shows that Europeans are 50 percent more likely than U.S. residents to buy “green” products indicating such differences on the environmental awareness².

In terms of global pollution, the scenario in which consumers are aware of both the domestic and the foreign emissions can be broadly interpreted as either consumers in one country becoming aware of the transboundary nature of pollution³ or becoming imperfectly altruistic in the sense that they care about the negative externality of foreign production on the population of the other country. In any case, the idea is that consumers in one country are concerned about the effects of global production on environmental quality.

All in all, this chapter sheds light to a novel mechanism which explains the persistence of leakage; I show that local environmental consciousness about local pollution increases the demand for the foreign good although the domestic firm produces employing a cleaner technology compared to a baseline case in which

²<http://www.livescience.com/4695-survey-europeans-green-americans.html>

³An example could be an environmental group’s campaign about pollution taking place in another country such as the “Detox campaign” by Greenpeace which took action to cut the hazardous chemicals that leak from clothing manufacturing processes and end up in the rivers in Mexico and China by informing consumers worldwide which clothing brands follow these practices (<http://www.greenpeace.org/international/en/campaigns/toxics/water/detox/>).

consumers are not environmentally aware. In terms of tackling leakage, I also examine the scenario where these local environmentally aware consumers care now about both local and foreign pollution. Indeed, the shift from local to global awareness mitigates the extent of emissions leakages as firms in both countries have the incentive to undertake abatement investments that reduce the emission intensities in both countries.

The remainder of this chapter is organised as follows. In section 2.2, I describe the model and the three different cases that I am examining i.e., the benchmark case in which consumers in both countries are consumption oriented, the case in which consumers in one country are environmentally conscious about the domestic emissions (local pollution) and the case in which these consumers care also about foreign emissions (global pollution). In section 2.3, I compare the different settings and present the results in terms of changes in the emissions intensity and output for each firm as well as the change in each country's pollution. Section 2.4 concludes.

2.2 The Model

This section introduces a two-country model which consists of country F and country NF. On the demand side, consider a representative consumer with a utility function of the form⁴:

$$U_j(q_{1j}, q_{2j}) = a(q_{1j} + q_{2j}) - \frac{b}{2}(q_{1j}^2 + 2\theta q_{1j}q_{2j} + q_{2j}^2) + m_j - k_j e_1 q_{1j} - x_j e_2 q_{2j}$$

where $a, b > 0$ and $j = \{F, NF\}$. m_j represents all other goods (numeraire good) and has a price normalised to $p_m = 1$. θ is the degree of substitutability of good 1 and good 2 and is assumed to be between $0 < \theta < 1$. This implies that the two goods are neither perfect substitutes ($\theta = 1$) nor independent in demand ($\theta = 0$). The parameter k denotes the degree of environmental consciousness about

⁴See Bowley (1924) or Martin (2002).

pollution generated in country F (local pollution) and x the degree of environmental consciousness about pollution generated in country NF. For $k, x > 0$, the consumer suffers a disutility by consuming the two goods based on the degree of their environmental awareness. I assume throughout this chapter that $k_{NF}, x_{NF} = 0$ so that consumers in country NF are entirely consumption oriented⁵. Inevitably, production of both goods generates pollution and $e_i = [0, 1]$ for $i = 1, 2$ is the emission intensity⁶.

Consumers face the following budget constraint $p_{1j}q_{1j} + p_{2j}q_{2j} + m_j = y$. Thus, by maximising the utility function for the representative consumer under the budget constraint, we can see that the market is characterised by the following linear inverse demand functions:

$$p_{1j} = a - b(q_{1j} + \theta q_{2j}) - ke_1, \quad p_{2j} = a - b(q_{2j} + \theta q_{1j}) - xe_2. \quad (2.1)$$

On the supply side, there are two firms performing under Cournot competition. Firm 1 produces good 1 and is located in country F whereas firm 2 produces good 2 and is located in country NF. I assume free trade between the two countries and the same non-negative marginal cost of production, c , for both firms⁷. Total transboundary pollution can be expressed as the aggregate emissions produced by both firms $E = e_1Q_1 + e_2Q_2$, where $Q_1 = nq_{1F} + (1 - n)q_{1NF}$ and $Q_2 = nq_{2F} + (1 - n)q_{2NF}$ for nq_{1F} (nq_{2F}) as the quantity of good 1 (good 2) consumed in country F and $(1 - n)q_{1NF}$ ($(1 - n)q_{2NF}$) the quantity of good 1 (good 2) consumed

⁵Again, as it is mentioned earlier, I assume that consumers in country F can be environmentally aware whereas those in country NF are consumption oriented since not only this is a common assumption in the literature but also, and more importantly, it is interesting to investigate the effects of such a difference in the degree of environmental awareness on the consumption choices, the leakage and the technology choice by the firms as well as on pollution.

⁶Here as well as in chapter 3, I model the technology choice as continuous in contrast with chapter 1 where it was a discrete choice; for papers with continuous technology choice see e.g. Dijkstra and Gil-Moltó (2014).

⁷I assume that there are fixed costs of quality improvement, while variable costs do not change with quality. This corresponds to one of the two cases analysed in the literature on product differentiation and can be thought of as a situation in which the firm engages in R&D and advertising activities to improve quality, see Motta (1993) among others.

in country NF. I assume that there is a mass n of consumers in country F and $(1 - n)$ in country NF and I denote by q_{1F} the individual demand for good 1 in country F and by q_{1NF} the individual demand for good 1 in country NF. Similarly, for good 2.

The profits for each firm can be defined as the variable profits minus the fixed costs related to the investment required to adopt an available technology:

$$\Pi_i = (p_{iF} - c)nq_{iF} + (p_{iNF} - c)(1 - n)q_{iNF} - \phi_i$$

where $\phi_i = \frac{\beta}{2}(1 - e_i)^2$ for $i = 1, 2$.

2.2.1 The Benchmark Case

First, I examine the case where consumers in both countries are not environmentally aware and, in other words they are totally consumption oriented, i.e., $k_F, k_{NF} = 0$ and $x_F, x_{NF} = 0$. Hence, for a representative consumer in country F:

$$U_F(q_{1F}, q_{2F}) = a(q_{1F} + q_{2F}) - \frac{b}{2}(q_{1F}^2 + 2\theta q_{1F}q_{2F} + q_{2F}^2) + m_F$$

and for a representative consumer in country NF:

$$U_{NF}(q_{1NF}, q_{2NF}) = a(q_{1NF} + q_{2NF}) - \frac{b}{2}(q_{1NF}^2 + 2\theta q_{1NF}q_{2NF} + q_{2NF}^2) + m_{NF}$$

which implies that using Eq. (2.1):

$$p_{1F} = a - b(q_{1F} + \theta q_{2F}), \quad p_{1NF} = a - b(q_{1NF} + \theta q_{2NF}).$$

and

$$p_{2F} = a - b(q_{2F} + \theta q_{1F}), \quad p_{2NF} = a - b(q_{2NF} + \theta q_{1NF}).$$

Solving for the demand functions, we get from $\frac{\partial \Pi_1^{(0)}}{\partial q_1} = 0$ and $\frac{\partial \Pi_1^{(0)}}{\partial q_2} = 0$ the

following:

$$q_1^{(0)} = \frac{(a-c)(2-\theta)}{b(4-\theta^2)}, \quad q_2^{(0)} = \frac{(a-c)(2-\theta)}{b(4-\theta^2)}.$$

Then, I can solve for the individual demand functions of each good in each country. Since both $k_F, k_{NF} = 0$ and $x_F, x_{NF} = 0$, we can easily see that

$$q_1^{*(0)} = q_{1F}^{*(0)} = q_{1NF}^{*(0)} = q_2^{*(0)} = q_{2F}^{*(0)} = q_{2NF}^{*(0)} = \frac{(a-c)(2-\theta)}{b(4-\theta^2)}. \quad (2.2)$$

Based on Eq. (2.2), we can write the total demand for good 1 and 2 respectively as

$$Q_1^{*(0)} = nq_{1F}^{*(0)} + (1-n)q_{1NF}^{*(0)} = \frac{(a-c)(2-\theta)}{b(4-\theta^2)} \quad (2.3)$$

$$Q_2^{*(0)} = nq_{2F}^{*(0)} + (1-n)q_{2NF}^{*(0)} = \frac{(a-c)(2-\theta)}{b(4-\theta^2)}. \quad (2.4)$$

Also,

$$Q_1^{*(0)} + Q_2^{*(0)} = \frac{2(a-c)(2-\theta)}{b(4-\theta^2)}. \quad (2.5)$$

It is straightforward that neither individual demand nor the total demand for each good is a function of e_1 or e_2 since consumers are not concerned about the pollution generated by the production of these two goods. Solving for the prices of the two goods in each country we obtain:

$$p_{1F}^{*(0)} = p_{1NF}^{*(0)} = p_{2F}^{*(0)} = p_{2NF}^{*(0)} = \frac{(2-\theta)[(a+c(1+\theta))]}{4-\theta^2}.$$

On the firms' side, the corresponding first order condition of the profit maximisation problem for each of them ($\frac{\partial \Pi_1}{\partial e_1} = 0$ and $\frac{\partial \Pi_2}{\partial e_2} = 0$) yields the equilibrium emission rate for each firm; that is,

$$e_1^{*(0)} = 1 \quad e_2^{*(0)} = 1 \quad (2.6)$$

which implies that both firms find it optimal to produce with the dirtiest technology. This result is intuitive since both firms have no incentives to incur any cost to adopt a cleaner technology as consumers care only about their consumption.

2.2.2 Local pollution

Now let us consider the case in which consumers in one of the two countries care about the domestic pollution. Suppose that this holds for consumers in country F i.e., $k_F > 0$, whereas consumers in country NF are still consumption-oriented i.e., for these consumers $k_{NF} = 0$ ⁸. In other words, consumers in country F are conscious about pollution generated by the production of the firm that is located in their country whereas consumers in the foreign country care solely about their consumption⁹. We could have consumers in both countries being environmentally aware with different levels of awareness but this asymmetry in the level of awareness can be simplified as having consumers in one country who are environmentally aware and in the other country they are not. Also, as in the benchmark case, I can calculate the optimal outputs and emission rates. Note that, in this case, the utility function of the representative consumer in country F is:

$$U_F(q_{1F}, q_{2F}) = a(q_{1F} + q_{2F}) - \frac{b}{2}(q_{1F}^2 + 2\theta q_{1F}q_{2F} + q_{2F}^2) + m_F - k_F e_1 q_{1F}$$

⁸The results are not affected qualitatively in case I assume that consumers in country F are consumption oriented and consumers in country NF are the ones who have become more environmentally aware.

⁹Here, I assume that all consumers in country F are environmentally aware. If only a proportion of them is environmentally conscious then the results would not be affected qualitatively. In particular, suppose that there is a χ percentage of the consumers in country F being environmentally aware. Then, for $\chi = 0$, this is equivalent to the benchmark case; for $\chi = 1$, this is equivalent to the case analysed in this section (Local pollution) and for $0 < \chi < 1$ then this would just add a scale factor to the results of the model.

while for the representative consumer in country NF it is the same as in the benchmark case since he/she is still consumption oriented:

$$U_{NF}(q_{1NF}, q_{2NF}) = a(q_{1NF} + q_{2NF}) - \frac{b}{2}(q_{1NF}^2 + 2\theta q_{1NF}q_{2NF} + q_{2NF}^2) + m_{NF}.$$

So now,

$$p_{1F} = a - b(q_{1F} + \theta q_{2F}) - k_F e_1, \quad p_{1NF} = a - b(q_{1NF} + \theta q_{2NF}).$$

and

$$p_{2F} = a - b(q_{2F} + \theta q_{1F}), \quad p_{2NF} = a - b(q_{2NF} + \theta q_{1NF}).$$

From $\frac{\partial \Pi_1^{(1)}}{\partial q_{1F}} = 0$ and $\frac{\partial \Pi_1^{(1)}}{\partial q_{1NF}} = 0$, I get:

$$q_{1F}^{(1)} = \frac{(a-c)(2-\theta) - 2k_F e_1}{b(4-\theta^2)} \quad \text{and} \quad q_{1NF}^{(1)} = \frac{(a-c)(2-\theta)}{b(4-\theta^2)} \quad (2.7)$$

and from $\frac{\partial \Pi_2^{(1)}}{\partial q_{2F}} = 0$ and $\frac{\partial \Pi_2^{(1)}}{\partial q_{2NF}} = 0$,

$$q_{2F}^{(1)} = \frac{(a-c)(2-\theta) + \theta k_F e_1}{b(4-\theta^2)} \quad \text{and} \quad q_{2NF}^{(1)} = \frac{(a-c)(2-\theta)}{b(4-\theta^2)}. \quad (2.8)$$

Recall, that in order to derive q_{1NF} and q_{2NF} I substitute $k_{NF}, x_{NF} = 0$. These demand functions allow us to write the total demand for good 1 as

$$Q_1^{(1)} = nq_{1F} + (1-n)q_{1NF} = \frac{(a-c)(2-\theta) - 2nk_F e_1}{b(4-\theta^2)}$$

and for good 2 as

$$Q_2^{(1)} = nq_{2F} + (1-n)q_{2NF} = \frac{(a-c)(2-\theta) + \theta nk_F e_1}{b(4-\theta^2)}.$$

By substituting the demand functions (Eq. (2.7) and (2.8)) of each good to the inverse demand functions p_1 and p_2 , we can solve for the prices of good 1 and good 2 which read¹⁰:

$$p_{1F}^{(1)} = \frac{(2 - \theta)[(a + c(1 + \theta)) - 2k_F e_1]}{4 - \theta^2}, \quad p_{1NF}^{(1)} = \frac{(2 - \theta)[(a + c(1 + \theta))]}{4 - \theta^2}$$

$$p_{2F}^{(1)} = \frac{(2 - \theta)[(a + c(1 + \theta)) + \theta k_F e_1]}{4 - \theta^2}, \quad p_{2NF}^{(1)} = \frac{(2 - \theta)[(a + c(1 + \theta))]}{4 - \theta^2}.$$

With regard to the firms, from the first order condition for profit maximisation for each firm ($\frac{\partial \Pi_1^{(1)}}{\partial e_1} = 0$ and $\frac{\partial \Pi_2^{(1)}}{\partial e_2} = 0$), we obtain the optimal emission rate for each firm; that is,

$$e_1^{*(1)} = \frac{\beta\epsilon - 4k_F\lambda}{\beta\epsilon - 8nk_F^2} \quad e_2^{*(1)} = 1 \quad (2.9)$$

where $\epsilon = b(4 - \theta^2)^2$ and $\lambda = n(a - c)(2 - \theta)$. The second order condition for a maximum requires that $\beta\epsilon > 8nk_F^2$ (see Appendix II) and thus for $e > 0$, the numerator of $e_1^{*(1)}$ has also to be positive, i.e., $\beta\epsilon > 4k_F\lambda$.

It is easily shown that $e_1^{*(1)} < 1$ since $\beta\epsilon - 4k_F\lambda < \beta\epsilon - 8nk_F^2$ implies that $2nk_F < \lambda$ which holds (see appendix I). Hence, firm 1 chooses to adopt a cleaner technology as a response to the local environmental awareness of consumers where that firm is located. Contrary, firm 2, with no incentives to employ a cleaner technology, continues producing with the dirty technology since k_F does not affect

¹⁰Note that $p_{1F} \neq p_{1NF}$ and $p_{2F} \neq p_{2NF}$ since consumers from different countries have different preferences and thus there is price discrimination by the firms. I assume that consumers cannot buy the same good from elsewhere except for their country and this is not an unrealistic assumption. One example can be goods with short expiry date, textbooks that it is illegal to purchase them from a different country/ continent due to copyright issues or goods that have different specifications in each country or do not include services such as warranty.

firm's 2 technology choice. This is intuitive since there are not any incentives for the firm to adopt a cleaner, but costly, technology as consumers in both countries are not concerned about the pollution generated by this firm. Additionally, the degree of substitutability between the two goods does not have any impact on firm's 2 technology choice.

We can also see that the market size in country F is negatively related to the emission rate chosen by firm 1

$$\frac{\partial e_1^{*(1)}}{\partial n} = \frac{4k_F\beta\epsilon(2k_F - \frac{\lambda}{n})}{(\beta\epsilon - 8nk_F^2)^2}$$

since the numerator is negative ($2k_F - \lambda/n < 0$) indicating that a larger pool of locally environmentally aware consumers stimulates the domestic firm to reduce more its emission intensity. Also, the sign in derivative of $e_1^{*(1)}$ with respect to θ is negative since

$$\frac{\partial e_1^{*(1)}}{\partial \theta} = \frac{16k_F\theta\beta\epsilon(2nk_F - \lambda)}{(\beta\epsilon - 8nk_F^2)^2}$$

where $(16k_F\theta\beta\epsilon) > 0$, $(2nk_F - \lambda) < 0$ and $(\beta\epsilon - 8nk_F^2)^2 > 0$. Thus, the effect of the degree of substitutability between the two goods on the domestic firm's emission rate is negative suggesting that when goods are becoming closer substitutes, firm 1 will choose to adopt a cleaner technology and vice versa.

Now, we can solve for the profit-maximising outputs of good 1 and good 2 which can be expressed as:

$$Q_1^{*(1)} = \frac{(a - c)(2 - \theta) - \frac{2nk_F(\beta\epsilon - 4k_F\lambda)}{\beta\epsilon - 8nk_F^2}}{b(4 - \theta^2)} \quad (2.10)$$

$$Q_2^{*(1)} = \frac{(a - c)(2 - \theta) + \frac{\theta nk_F(\beta\epsilon - 4k_F\lambda)}{\beta\epsilon - 8nk_F^2}}{b(4 - \theta^2)}. \quad (2.11)$$

Also,

$$Q_1^{*(1)} + Q_2^{*(1)} = \frac{2(a - c)(2 - \theta)}{b(4 - \theta^2)} - \frac{nk_F(\beta\epsilon - 4k_F\lambda)}{b(\beta\epsilon - 8nk_F^2)(2 + \theta)}. \quad (2.12)$$

Lemma 2.1. $Q_1^{(1)}$ ($Q_2^{(1)}$) is lower (higher) for $k_F > 0$ than for $k_F = 0$.

Proof. Comparing Eq. (2.10) and (2.11) with Eq. (2.3) and (2.4) respectively, we can see that $Q_1^{(1)} < Q_1^{(0)}$ since

$$\frac{(a-c)(2-\theta) - \frac{2nk_F(\beta\epsilon - 4k_F\lambda)}{\beta\epsilon - 8nk_F^2}}{b(4-\theta^2)} < \frac{(a-c)(2-\theta)}{b(4-\theta^2)}$$

and $Q_2^{(1)} > Q_2^{(0)}$ since

$$\frac{(a-c)(2-\theta) + \frac{\theta nk_F(\beta\epsilon - 4k_F\lambda)}{\beta\epsilon - 8nk_F^2}}{b(4-\theta^2)} > \frac{(a-c)(2-\theta)}{b(4-\theta^2)}.$$

□

The intuition is simple. When consumers in country F care about the pollution generated by the good produced domestically (good 1), they reduce the quantity they demand for it. Also and more importantly, this encourages them to turn their consumption towards good 2 which is produced in the other country (recall that these consumers only care about the domestic damage). In particular, in the case of environmental consciousness of domestic pollution in country F (that is, $k_F > 0$), good 2 has increased demand ($Q_2^{(1)}$) since consumers prefer to buy the good whose production emissions do not affect them directly.

At this point we can highlight that this environmental consciousness of only the domestic pollution which leads to a turn by consumers in country F towards good 2 after the increase in k_F , creates leakage. As a result, pollution is increased in country NF since demand for good 2 is greater and firm 2 continues to produce employing the dirty technology. Thus, this chapter indicates that, in such a context, environmental consciousness of the local damage only can be considered as an additional factor which creates leakage, apart from those already mentioned in the literature, such as domestic taxation, unilateral climate policies and border adjustments.

2.2.3 Global/ Transboundary pollution

Let us now examine the case in which consumers in country F care not only about domestic pollution as in the previous case ($k_F > 0$) but also about foreign pollution ($x_F > 0$). It can be interpreted as the case of global pollution where consumers in country F care as much about foreign and as about domestic pollution ($k_F = x_F > 0$) or the case of transboundary pollution where these consumers care about foreign pollution but not as much as domestic pollution ($k_F > x_F > 0$). Now, the utility function of the representative consumer in country F is:

$$U_F(q_{1F}, q_{2F}) = a(q_{1F} + q_{2F}) - \frac{b}{2}(q_{1F}^2 + 2\theta q_{1F}q_{2F} + q_{2F}^2) + m_F - k_F e_1 q_{1F} - x_F e_2 q_{2F}$$

while for the representative consumer in country NF it is:

$$U_{NF}(q_{1NF}, q_{2NF}) = a(q_{1NF} + q_{2NF}) - \frac{b}{2}(q_{1NF}^2 + 2\theta q_{1NF}q_{2NF} + q_{2NF}^2) + m_{NF}$$

and

$$p_{1F} = a - b(q_{1F} + \theta q_{2F}) - k_F e_1, \quad p_{1NF} = a - b(q_{1NF} + \theta q_{2NF})$$

and

$$p_{2F} = a - b(q_{2F} + \theta q_{1F}) - x_F e_2, \quad p_{2NF} = a - b(q_{2NF} + \theta q_{1NF}).$$

meaning that here I assume $k_F, x_F > 0$ and $k_{NF}, x_{NF} = 0$. Again, we can solve for the individual and total demands for the two goods,

$$q_{1F}^{(2)} = \frac{(a - c)(2 - \theta) - 2k_F e_1 + \theta x_F e_2}{b(4 - \theta^2)}, \quad q_{1NF}^{(2)} = \frac{(a - c)(2 - \theta)}{b(4 - \theta^2)},$$

$$q_{2F}^{(2)} = \frac{(a-c)(2-\theta) + \theta k_F e_1 - 2x_F e_2}{b(4-\theta^2)} \quad q_{2NF}^{(2)} = \frac{(a-c)(2-\theta)}{b(4-\theta^2)}$$

and

$$Q_1^{(2)} = nq_{1F} + (1-n)q_{1NF} = \frac{(a-c)(2-\theta) + n[\theta x_F e_2 - 2k_F e_1]}{b(4-\theta^2)},$$

$$Q_2^{(2)} = nq_{2F} + (1-n)q_{2NF} = \frac{(a-c)(2-\theta) + n[\theta k_F e_1 - 2x_F e_2]}{b(4-\theta^2)}.$$

The price of each good now is:

$$p_{1F}^{(2)} = \frac{(2-\theta)[(a+c(1+\theta)) - 2k_F e_1 + \theta x_F e_2]}{4-\theta^2}, \quad p_{1NF}^{(2)} = \frac{(2-\theta)[(a+c(1+\theta))]}{4-\theta^2}$$

$$p_{2F}^{(2)} = \frac{(2-\theta)[(a+c(1+\theta)) - 2x_F e_2 + \theta k_F e_1]}{4-\theta^2}, \quad p_{2NF}^{(2)} = \frac{(2-\theta)[(a+c(1+\theta))]}{4-\theta^2}$$

which illustrates again that firms are able to price-discriminate and extract more consumer surplus because of consumers' asymmetry in their environmental awareness between the two countries. We can also calculate the new optimal emission rates for both firm 1 and firm 2, following the same steps as in the previous section but now for $x_F > 0$ to end up with the following reacting functions:

$$e_1^{(2)} = \frac{\beta\epsilon - 4k_F\lambda - 4n\theta k_F x_F e_2}{\beta\epsilon - 8nk_F^2}, \quad e_2^{(2)} = \frac{\beta\epsilon - 4x_F\lambda - 4n\theta k_F x_F e_1}{\beta\epsilon - 8nx_F^2}. \quad (2.13)$$

These reaction functions reveal that the emission rates of each firm are not independent from each other since the environmental consciousness of consumers in country F for both domestic pollution (k_F) and pollution in country NF (x_F) affects the demand for each good and, thus, the technology choice by the firm as well as the output generated. Also, the derivative of $e_1^{(2)}$ with respect to $e_2^{(2)}$ is negative $\frac{\partial e_1^{(2)}}{\partial e_2^{(2)}} = \frac{-4n\theta k_F x_F}{\beta\epsilon - 8nk_F^2} < 0$ and, hence, domestic and foreign emissions are strategic substitutes. By solving this system of equations for $e_1^{(2)}$ and $e_2^{(2)}$, we obtain

the following:

$$e_1^{*(2)} = \frac{(\beta\epsilon - 8nx_F^2)(\beta\epsilon - 4k_F\lambda) - 4n\theta k_F x_F(\beta\epsilon - 4x_F\lambda)}{(\beta\epsilon - 8nk_F^2)(\beta\epsilon - 8nx_F^2) - (4n\theta k_F x_F)^2},$$

$$e_2^{*(2)} = \frac{(\beta\epsilon - 8nk_F^2)(\beta\epsilon - 4x_F\lambda) - 4n\theta k_F x_F(\beta\epsilon - 4k_F\lambda)}{(\beta\epsilon - 8nk_F^2)(\beta\epsilon - 8nx_F^2) - (4n\theta k_F x_F)^2}.$$

From the stability condition (see appendix II), we get that $(\beta\epsilon - 8nk_F^2)(\beta\epsilon - 8nx_F^2) > (4n\theta k_F x_F)^2$ and thus the numerators of $e_1^{*(2)}$ and $e_2^{*(2)}$ have also to be positive in order to have $e_1^{*(2)}$ and $e_2^{*(2)}$ positive.

Then, by using Eq. (2.13), we can express the profit-maximising outputs as:

$$Q_1^{*(2)} = \frac{(a-c)(2-\theta) + n\theta x_F e_2^{**} - 2nk_F e_1^{**}}{b(4-\theta^2)} = \quad (2.14)$$

$$\frac{(a-c)(2-\theta) + \frac{n\theta x_F(\beta\epsilon - 8nk_F^2)(\beta\epsilon - 4x_F\lambda) - 4n\theta k_F x_F(\beta\epsilon - 4k_F\lambda)}{(\beta\epsilon - 8nk_F^2)(\beta\epsilon - 8nx_F^2) - (4n\theta k_F x_F)^2} - \frac{2nk_F(\beta\epsilon - 8nx_F^2)(\beta\epsilon - 4k_F\lambda) - 4nk_F\theta x_F(\beta\epsilon - 4x_F\lambda)}{(\beta\epsilon - 8nk_F^2)(\beta\epsilon - 8nx_F^2) - (4n\theta k_F x_F)^2}}{b(4-\theta^2)}$$

$$Q_2^{*(2)} = \frac{(a-c)(2-\theta) - 2nx_F e_2^{**} + nk_F \theta e_1^{**}}{b(4-\theta^2)} = \quad (2.15)$$

$$\frac{(a-c)(2-\theta) - \frac{2nx_F(\beta\epsilon - 8nk_F^2)(\beta\epsilon - 4x_F\lambda) - 4n\theta k_F x_F(\beta\epsilon - 4k_F\lambda)}{(\beta\epsilon - 8nk_F^2)(\beta\epsilon - 8nx_F^2) - (4n\theta k_F x_F)^2} + \frac{nk_F\theta(\beta\epsilon - 8nx_F^2)(\beta\epsilon - 4k_F\lambda) - 4nk_F\theta x_F(\beta\epsilon - 4x_F\lambda)}{(\beta\epsilon - 8nk_F^2)(\beta\epsilon - 8nx_F^2) - (4n\theta k_F x_F)^2}}{b(4-\theta^2)}$$

and the total demand for both goods as:

$$Q_1^{*(2)} + Q_2^{*(2)} = \frac{2(a-c)(2-\theta)}{b(4-\theta^2)} + \frac{n(k_F - x_F)\beta\epsilon[\beta\epsilon + 4nk_F x_F(2-\theta) - 4(k_F + x_F)\lambda]}{b(2+\theta)[(\beta\epsilon - 8nk_F^2)(\beta\epsilon - 8nx_F^2) - (4n\theta k_F x_F)^2]}. \quad (2.16)$$

2.3 Comparison of the cases

The purpose of this section is to compare the results of the previous cases and examine the changes in outputs, technology choices and both each country's and aggregate pollution. Let us first start with the changes in the emission rates.

Proposition 2.1. *For firm 1,*

$$\Delta e_1' = e_1^{*(1)} - e_1^{*(0)} < 0, \quad \Delta e_1'' = e_1^{*(2)} - e_1^{*(1)} < 0.$$

For firm 2,

$$\Delta e_2' = e_2^{*(1)} - e_2^{(0)} = 0, \quad \Delta e_2'' = e_2^{*(2)} - e_2^{*(1)} < 0.$$

Proof. See Appendix III. □

Proposition 2.1 states that firm's 1 emission intensity is reduced when consumers in the country where this firm is located care about the local emissions and shift their consumption to good 2. Interestingly, it is reduced even more after these consumers care also about foreign pollution, although it is not directly affected (only indirectly) by x_F . This could be explained taking into account that when consumers in country F care about both domestic and foreign pollution, firm 1 produces more, as it will be shown in Proposition 2.2, and this, in turn, makes it worthwhile for firm 1 to employ a cleaner technology. For firm 2, we can see that it chooses to employ the dirtiest technology when consumers are not conscious about the pollution in country NF since there is no incentive to incur the cost and do otherwise. However, when consumers in country F care about both domestic and foreign emissions and thus their demands depend on e_2 , firm 2 finds it optimal to adopt a cleaner technology.

Regarding the changes in the outputs, I can show that:

Proposition 2.2. *For firm 1,*

$$\Delta Q_1' = Q_1^{*(1)} - Q_1^{*(0)} < 0, \quad \Delta Q_1'' = Q_1^{*(2)} - Q_1^{*(1)} > 0$$

For firm 2,

$$\Delta Q_2' = Q_2^{*(1)} - Q_2^{*(0)} > 0, \quad \Delta Q_2'' = Q_2^{*(2)} - Q_2^{*(1)} < 0.$$

Proof. See Appendix III. □

According to Proposition 2.2, when consumers in country F care only about domestic pollution ($k_F > 0, x_F = 0$) they turn their consumption towards the good produced abroad (leakage) although the domestic firm tries to counteract the reduction in its demand by employing a cleaner technology. For $k_F > 0, x_F > 0$, the equilibrium output produced by the domestic firm is increased whereas the equilibrium output produced by firm 2 is reduced. In particular, domestic consumers now take into account the pollution from good 2 and thus the demand for it is lower contrary to good 1 whose demand rises since domestic consumers shift part of their demand from good 2 to good 1. Combining the two propositions, firm 1 has optimally chosen to produce more but with a cleaner technology whereas firm 2 decreased both the emissions rate, since consumers now care about the pollution generated in country NF, and the quantity supplied, since consumers are turning their consumption again towards good 1.

Based on the above, we could also comment on the consumer surplus under the three scenarios. Specifically, consumer surplus in country F in the local pollution case is reduced compared to the benchmark case due to the decrease in the output by firm 1 whereas the opposite holds for consumers in country NF. Contrary, in the global/transboundary pollution case, consumer surplus for consumers in country F is increased relative to the local awareness case and for consumers in country NF is decreased. In terms of total surplus, for $k_F > 0, x_F = 0$, it is reduced since aggregate output is lower whereas for both $k_F > 0, x_F > 0$ it is higher due to the increase in total output.

Finally, I can observe the differences in each country's and the aggregate pollution.

Proposition 2.3. *For $\{k_F > 0, x_F = 0\}$, pollution in country NF is increased but aggregate pollution is lowered. For $\{k_F > 0, x_F > 0\}$, pollution in country NF is reduced and leakage is diminished.*

Proof. See Appendix III. □

When consumers in country F care about domestic pollution which is produced by the firm located there, they consume more of the good produced by the foreign firm. Responding to this change of preferences for consumers in country F, firm 1 chooses to produce employing a cleaner technology compared to the one in the benchmark setting. Contrary, firm 2 continues to produce with the dirtiest technology and increase its output since its demand is higher and hence has no incentive to change the dirty technology it uses.

Thus, pollution in country F is reduced because both equilibrium emission rate and output are decreased whereas pollution in country NF is increased (leakage) because output is increased and firm 2 is producing employing the dirtiest technology. However, it is remarkable that total production ($Q_1 + Q_2$) in this case is reduced¹¹ and since the emission rates are lowered (stable by firm 2 but decreased for firm 1), then aggregate pollution is also lowered.

For $k_F > 0$, $x_F > 0$ consumers in country F, who are now conscious about both domestic and foreign emissions are discouraged from consuming the polluting good (good 2) and the leakage phenomenon is diminished. Indeed, quantity demanded for good 2 and the emission rate chosen by firm 2 are reduced and thus pollution in country NF is lowered.

2.4 Conclusion

This chapter explores how environmental consciousness of consumers in the domestic market about the local pollution may create leakage in a setting with two countries and shows that this could be an additional cause other than those proposed in the literature. In particular, I investigate the effect of having consumers in one country who care about only domestic pollution on the demand for the domestic and foreign

¹¹Eq. (2.5) along with Eq. (2.12) show that total quantity produced by both firms is lowered in this case by this amount $\frac{nk_F(\beta\epsilon - 4k_F\lambda)}{b(\beta\epsilon - 8nk_F^2)(2+\theta)}$.

good and on the endogenous technology choice by the firms. I find that consumers shift their demand to the good produced abroad, even though the domestic firm tries to offset the contraction in its demand by employing a cleaner technology. This results to leakage since there is increased pollution in country NF due to production in that country taking place with the dirtiest technology.

It is interesting to note that this scenario implies that aggregate output and pollution (i.e., the sum of pollutants formed in both countries) are lower compared to the benchmark setting in which consumers are totally consumption oriented, because the aggregate emission intensity is reduced along with a decrease in output. In terms of tackling leakage, I examine the case in which domestic consumers care about both domestic and foreign emissions. The shift from local to global consciousness indeed mitigates the extent of emission leakage as firms in both countries have the incentive to undertake abatement investments that decline the emission intensity in both countries.

Chapter 3

Green alliances

3.1 Introduction

Examples of environmental organisations clashing with businesses are surely not scarce. One of the environmental groups' common practices which affect market outcomes and consumers' choices as well as environmental quality is to increase consumers' awareness via campaigns¹. For instance, Greenpeace campaigned against the construction of a new runway in London Heathrow airport as it would have derailed efforts to cut carbon emissions. Additionally, as part of its campaign for the oil drilling in the Arctic, it has targeted both Lego over its partnership with oil corporation, Shell and the largest oil and gas company in the world, the Russian energy provider Gazprom.

The idea of environmentalists conflicting with firms and how this antagonistic relationship can affect environmental quality and social welfare have already been investigated by a large strand of literature (see Friehe, 2013; Sartzetakis *et al.*, 2012; Petrakis *et al.*, 2005; Heyes and Maxwell, 2004; Liston-Heyes, 2001 among others). Heijnen and Schoonbeek (2008) examine a market in which a monopolistic firm

¹Other tools for educating consumers about the environmental impacts of a product's manufacture apart from an EG's campaign include price signalling of the high quality/ greener good (see e.g. Mahenc, 2008), ecolabels (see e.g. Teisl *et al.*, 2002) and firms' own advertising to assist buyers to learn about the intangible characteristics of a product.

supplies an environmentally unfriendly good and characterise the equilibrium of an entry deterrence game where an environmental group (EG henceforth) can enter the market and set up a campaign to inform consumers about the environmental damage. They find that the aggregate environmental damage is lowest if the firm is able to deter entry of the environmentalists and the group's fixed entry cost is small enough. Van der Made and Schoonbeek (2009) consider a model of vertical product differentiation where consumers care about the environmental damage their consumption causes. Similarly to the previously mentioned paper, an EG is capable of increasing consumers' environmental concern via a campaign and they show that a prospect of such a campaign can induce entry by a firm that employs a cleaner production practice and may result in higher aggregate pollution due to an increase in production offsetting the decline in emissions. Heijnen (2013) investigates the incentives that the group has to inform consumers while Van der Made (2014) studies how these incentives are affected by the level of competition in the market. On the empirical side, Binder and Neumayer (2005) find that an EG's strength is effective in reducing air pollution levels in the form of SO_2 , smoke and heavy particulates in a setting where the group can influence the policymakers.

However, in recent years this relationship has evolved. "Green alliances", namely partnerships between an EG and a firm have become a popular phenomenon for various reasons. From a firm's perspective, its lack of expertise or public trust in addressing adequately environmental problems as well as the attempt to pre-empt attacks from environmental groups, the government and the media, provide substantial incentives to establish cooperation. Alliances with EGs can also be a source of information and knowledge about innovative ways to rethink production technologies, identify new products and address stakeholder concerns. In fact, it may even be the only choice to access the knowledge held by the environmentalists, since firms' internal development of such expertise may be too costly, inefficient or time-consuming, and merger with or acquisition of an EG is highly unlikely (Rondinelli and London, 2003). For the group, these alliances may

offer more effective and efficient solutions than lobbying or campaigning against firms since, in an alliance, firms contribute to setting the environmental goals and hence their commitment to them can be stronger (Hartman and Stafford, 1997). Also, competitors may follow the lead and adopt a similar practice which strengthens even further the benefits of the partnership.

There are different types of green alliances such as licencing, in which case the firm produces using the EG's brand name, or product endorsement where the EG approves a firm's product as being environmentally friendly. In this chapter, I am focusing on the so-called "green system alliances" or "task forces", according to which the environmentalists assist the firm to develop and implement economically-feasible environmental programmes for the use of greener technologies.

Historically, the first (and unique at the time) partnership was between the Environmental Defence Fund (EDF) and McDonald's in 1990. EDF decided to take no money from McDonald's in order to be able to examine their business practices objectively and make the data open to the public. The EG had successfully helped the chain through a waste reduction action plan to administer cost saving programmes such as replacing polystyrene clamshell boxes with recycled materials. As a result, McDonald's recycled one million tons of corrugated boxes, reduced packaging by £300 million and decreased waste from restaurants by 30 percent. Since then, partnerships have become more popular. EDF joined forces with more firms i.e., FedEx, Walmart and the private equity firm KKR. Greenpeace also followed the initiative by helping Npower –a company owned by RWE, the German utility company– to promote Juice, a renewable energy product, to thousands of consumers in the UK as a clean energy option. The other two partnerships it did were a campaign with the Co-op Bank to remove PVC in credit cards and another with the retailer Iceland to promote their greenhouse gas friendly "Kyoto" refrigerators.

To the best of my knowledge, albeit the conflict scenario is well explored in the literature, the collaboration case has not been modelled yet. There are papers and reports, mainly in the managerial literature which focus on such an

endeavour, evaluating its benefits and weaknesses and providing suggestions for future initiatives. However, no economic model exists which describes the EG's strategy and what affects its decisions. Therefore, this chapter provides the first formal analysis of green alliances. In particular, I present a model in which the environmental group has two options: to campaign against a polluting firm which would shrink consumers' demand for the firm's product or to join forces with the firm which would reduce the cost of implementing a greener technology. The group bases its decision on which option results in lower total emissions.

In the model, the environmentalists' decision is affected by an environmental tax set at the outset by the government. One of the main results of my analysis is that higher taxation makes the conflict option more likely to be adopted by the EG. In other words, collaboration and a more stringent environmental policy are substitutes. Since emissions intensity is higher under conflict than under collaboration, this result uncovers a previously unexplored, possibly adverse effect of strengthening emissions taxation on environmental quality.

The government sets the environmental tax and aims to maximise social welfare which is defined as the sum of consumer and producer surplus minus the negative externality from pollution. These three components are attached with weights which represent the "ideological" inclination of the government or the relative importance of each for the government. Due to the complexity of the problem, I resort to numerical examples to calculate the optimal tax rate that maximises social welfare. I find that the optimal tax rate in the case where conflict is the only option for the environmentalists (i.e., the only case examined by the previous literature) is higher compared to the case where taxation affects the EG's choice between conflict and collaboration. The optimised level of social welfare is also higher in the latter case.

The remaining of the chapter is organised as follows. Subection 3.2.1 presents the model, while in subsection 3.2.2, I solve for the firm's optimal choice. In the next subsection (3.2.3), I solve for the environmental group's optimal decision and discuss how it is affected by the environmental tax. In subsection 3.2.4, I introduce the social

welfare function the government aims to maximise and I present numerical examples of the optimal tax rate. I also show how the optimal tax rate is affected by changes in relevant parameters of the model (subsection 3.2.5). Section 3.3 concludes.

3.2 The model

In this section I present the model and the firm's and environmental group's optimal choices and discuss how the EG's decision is affected by the environmental tax.

3.2.1 Preference, technology and strategies

Consider a market with a profit-maximising monopolist whose production of a single good pollutes the environment with an emission intensity (i.e., emissions per unit of product) denoted by $e > 0$. For simplicity, market demand is linear, $p = a^i - q$, where $a^i > 0$ and q denotes quantity. I denote by $\gamma > 0$ the component of the monopolist's unit cost of production which is independent of the environmental characteristics of the production technology chosen by the firm. The firm's emissions are taxed by the government at the tax rate $t \geq 0$.

In this market, an environmental group (EG) aims at minimising total emissions, eq , by choosing between two options². It can conflict with the monopolist by campaigning against it. In such a case, the campaign will induce a certain degree of environmental awareness among consumers which will cause a reduction of the demand parameter a^i from $a > 0$ to $a\delta$ where δ is a random variable uniformly distributed over the interval $[h, 1]$ with density function $f(\delta)$ ³. The alternative

²I assume that both options entail the same cost for the group (either monetary or psychological). This is due to the need for tractability and to guarantee a closed form solution for δ .

³Here, δ is stochastic but not a function of pollution. An interesting extension would be to have δ a function of the level of pollution so that we can assume that the more polluted the environment is, the more likely it is that consumers become more aware of pollution and that the group's campaign is more effective. However, for tractability reasons, I leave this extension for future research.

Another point related to this is the following. One could argue that since production is restricted

option for the EG is to collaborate with the firm by sharing its know-how on the adoption of the greener technology, thus facilitating the firm in reducing the unit cost of adopting a cleaner technology. Formally, I assume that the monopolist's unit cost of production has a second component, inversely related to the emission intensity of the adopted technology, $z^i \frac{1}{e}$. Collaboration with the EG reduces the parameter z^i from $z > 0$ to zm where $m \in (0, 1)$. Based on these assumptions, the firm's profits can be written as follows:

$$\Pi_i = (a^i - q)q - teq - z^i \frac{1}{e}q - \gamma q$$

for $i = \{conf, coll\}$ which is an index denoting the EG's optimal decision between conflict and collaboration⁴.

under a monopolistic market then the group may have stronger incentives to collaborate rather than to conflict with the monopolist because the campaign against the firm will not be effective. However, in this model there is an interesting aspect in having a monopolist. If we assume that the potential awareness of consumers is increasing in the level of pollution, a campaign against the polluters (conflict) will be more likely (compared to collaboration) in a competitive market than in a monopoly.

Also, in the case where there would be no monopoly distortion and for example, the monopolist could perfectly discriminate and extract all the consumer surplus, the results would not be affected qualitatively. It is just the fact that now the monopolist would be a total surplus maximiser (compared to a profit maximiser) where total surplus still depends on the height of the demand (which depends on conflict or collaboration) and the technology employed.

⁴As previously discussed, the decision of the EG here is on whether to conflict or collaborate with the firm. One could argue that an alternative to this conflict vs. collaboration case could be the scenario where, instead of conflict, the group can offer a contract threatening conflict to the firm unless a satisfactory level of emissions is achieved. However, this may not be possible in reasonable circumstances. For instance, there may be frictions that make such a contract unfeasible such as the fact that the EG may become less effective in mobilising activists at a later date or that the negotiations sustained by the threat of conflict take time and δ is different in the future and thus the group risks the effectiveness of the threatening campaign; therefore they prefer to campaign rather than negotiate. In any case, even if this alternative case was a possible option, the main results would not be qualitatively affected. If, in the parameter region where the group prefers conflict to collaboration, the group now prefers negotiations to collaboration then the targeted level of emissions is likely to be the low level of emissions under conflict. So if the negotiations sustained by the threat of conflict are successful and indeed there is a low level of emissions achieved, this implies that output is restricted with respect to collaboration. From a social planner's point of view, the trade off between a potentially suboptimal low of output and low emission intensity under the threatening contract case and the low level of emission intensity and higher output under the collaboration case is qualitatively similar to then one presented in this model i.e. increased emission intensity and lower output under conflict compared to low level of emission intensity and higher output under collaboration. Thus, the effect of tax on the decision of the EG will work in the same way. In other words, in my model, a higher tax will make conflict more likely to happen

The timing of events is as follows. In stage one, the government sets the emissions tax rate t . In stage two, uncertainty on δ (i.e., the inverse measure of effectiveness of the conflict option) is resolved and, based on this, the EG decides whether to conflict or collaborate with the firm⁵. In the third stage, the firm optimally chooses the emission intensity e and output q .

3.2.2 The monopolist's decision

Proceeding by backward induction from the third stage, the maximisation of the monopolist's profits with respect to q and e gives us:

$$\frac{\partial \Pi_i}{\partial q} = a^i - \gamma - 2q - te - \frac{z^i}{e} = 0 \Leftrightarrow q = \frac{a^i - \gamma - te - \frac{z^i}{e}}{2}, \quad (3.1)$$

$$\frac{\partial \Pi_i}{\partial e} = -tq + \frac{z^i}{e^2}q = 0 \Leftrightarrow e = \sqrt{\frac{z^i}{t}}. \quad (3.2)$$

Substituting (3.2) in (3.1) we obtain the optimal quantity

$$q_i = \frac{a^i - \gamma - 2\sqrt{z^i t}}{2}$$

or explicitly, under the two alternative scenarios of conflict or collaboration,

$$q_{conf} = \frac{a\delta - \gamma - 2\sqrt{zt}}{2} \quad \text{and} \quad q_{coll} = \frac{a - \gamma - 2\sqrt{zmt}}{2}. \quad (3.3)$$

and in this alternative case the group would go for the negotiations.

⁵In this model, I assume uncertainty about the size of δ . In a more complete model, there could be other parameters relative to the effectiveness of the choice of the group that are ex ante uncertain, for instance m . In such a case, the analysis and the derivation of a threshold is similar. In

particular, there is $\hat{m} = \left\{ \frac{\frac{a-\gamma}{2\sqrt{zt}} - \sqrt{\left(\frac{a-\gamma}{2\sqrt{zt}}\right)^2 - 4\left(\frac{a\delta-\gamma}{2\sqrt{zt}} - 1\right)}}{2} \right\}^2$ above which the EG would choose conflict

and below which it would choose to collaborate. Due to non linearity, the effect of the tax on the threshold is not apparent; however numerical examples show that the results hold qualitatively, i.e. a higher tax makes the scenario of the EG conflicting with the firm more likely.

As we can see from (3.3), the quantity produced in the collaboration case is positively affected by the reduction of the unit cost of employing a greener technology. In other words, collaboration reduces the firm's emission intensity but increases its total production. On the contrary, in the conflict case, the action of the EG just causes a contraction in demand (by the factor δ) and hence in firm's total production, for given emission intensity. Therefore, it is apparent that the output under collaboration is higher than the output under conflict.

Firm's profits can be written as

$$\Pi_i = \frac{(a^i - \gamma - 2\sqrt{z^i t})^2}{4}$$

and total emissions as

$$e_i q_i = \frac{a^i - \gamma - 2\sqrt{z^i t}}{2} \sqrt{\frac{z^i}{t}}.$$

It is easy to show that equilibrium quantity, emission rate, profits and total emissions are all negatively affected by the environmental tax. As the tax rate increases, the firm has a stronger incentive to lower emissions by employing a cleaner technology. However, the overall unit cost of production increases causing a reduction in the optimal production level and in the firm's profits.

By comparing the firm's equilibrium profits under the two alternative scenarios of conflict and collaboration, it is easy to see that the firm always prefers collaborating with the EG:

$$\Pi_{coll} = \frac{(a - \gamma - 2\sqrt{zmt})^2}{4} > \Pi_{conf} = \frac{(a\delta - \gamma - 2\sqrt{zt})^2}{4}.$$

3.2.3 The EG's decision

On the environmentalists' side, the following assumption ensures that the production expanding effect of collaboration is dominated by the reduction in the emission intensity so that, for given demand conditions, collaboration always decreases total

emissions. Recalling that the objective of the EG is simply to minimise total emissions, it is clear that without Assumption 1 the EG would trivially prefer to conflict with the firm.

Assumption 3.1. *The parameter space is restricted by the following inequality*
 $ah - \gamma \geq 4\sqrt{zt}$.

In the Appendix, I show that Assumption 1 implies that, for given demand conditions, collaboration always reduces total emissions (see Appendix IV).

The EG will choose to collaborate with the firm if the total emissions generated under collaboration are lower than total emissions under conflict, $eq_{coll} < eq_{conf}$, which requires

$$\frac{a^i - \gamma - 2\sqrt{zmt}}{2} \sqrt{\frac{zm}{t}} < \frac{a^i - \gamma - 2\sqrt{zt}}{2} \sqrt{\frac{z}{t}}. \quad (3.4)$$

From the inequality (3.4) we derive a threshold value for δ , $\hat{\delta}$, above which the EG prefers to collaborate with the firm,

$$(a - \gamma - 2\sqrt{zmt})\sqrt{m} < a\delta - \gamma - 2\sqrt{zt} \Rightarrow (a - \gamma - 2\sqrt{zmt})\sqrt{m} + \gamma + 2\sqrt{zt} < a\delta$$

$$\delta > \frac{(a - \gamma - 2\sqrt{zmt})\sqrt{m} + \gamma + 2\sqrt{zt}}{a} \equiv \hat{\delta}. \quad (3.5)$$

Hence, the EG will choose

$$\begin{cases} \text{conflict} & \text{if } \delta \in [h, \hat{\delta}) \\ \text{collaborate} & \text{if } \delta \in (\hat{\delta}, 1] \end{cases}$$

We can easily check that Assumption 1 guarantees that $\hat{\delta} < 1$:

$$\frac{(a - \gamma - 2\sqrt{zmt})\sqrt{m} + \gamma + 2\sqrt{zt}}{a} < 1 \Rightarrow (a - \gamma - 2\sqrt{zmt})\sqrt{m} < a - \gamma - 2\sqrt{zt}$$

which holds as long as $(ah - \gamma) > 4\sqrt{zt}$ (see Assumption 1).

Let us now investigate the condition under which $\hat{\delta} > h$. Recall that the

parameter m (i.e. the inverse measure of effectiveness of collaboration) was initially assumed to be restricted in the interval $(0, 1)$. We show below that m should be above a threshold value $0 < m^* < 1$ to guarantee that $\hat{\delta} > h$ holds; in other words, $m \in (m^*, 1)$.

Imposing

$$\hat{\delta} = \frac{(a - \gamma - 2\sqrt{zmt})\sqrt{m} + \gamma + 2\sqrt{zt}}{a} > h \Rightarrow$$

we get

$$-2m\sqrt{zt} + (a - \gamma)\sqrt{m} - [ah - \gamma - 2\sqrt{zt}] > 0. \quad (3.6)$$

The LHS of Eq. (3.6) can be rewritten as

$$-m + \frac{a - \gamma}{2\sqrt{zt}}\sqrt{m} - \left(\frac{ah - \gamma}{2\sqrt{zt}} - 1 \right).$$

Defining $\sqrt{m} = \mu$, we find the two following roots of this quadratic polynomial⁶ which read

$$\mu_{1,2}^* = \frac{\frac{a-\gamma}{2\sqrt{zt}} \pm \sqrt{\left(\frac{a-\gamma}{2\sqrt{zt}}\right)^2 - 4\left(\frac{ah-\gamma}{2\sqrt{zt}} - 1\right)}}{2}.$$

Since $m \in (0, 1)$ then $\mu \in (0, 1)$. One of the roots is ruled out since it exceeds 1 (recall that $a - \gamma > 2\sqrt{zt}$). Thus, the only root is

$$\mu^* = \frac{\frac{a-\gamma}{2\sqrt{zt}} - \sqrt{\left(\frac{a-\gamma}{2\sqrt{zt}}\right)^2 - 4\left(\frac{ah-\gamma}{2\sqrt{zt}} - 1\right)}}{2}. \quad (3.7)$$

⁶For these to be real roots

$$\begin{aligned} \left(\frac{a-\gamma}{2\sqrt{zt}}\right)^2 > 4\frac{ah-\gamma}{2\sqrt{zt}} - 4 &\Rightarrow \left(\frac{a-\gamma}{2\sqrt{zt}}\right)^2 + 4 > 2\frac{ah-\gamma}{\sqrt{zt}} \Rightarrow \\ \left(\frac{a-\gamma}{2\sqrt{zt}}\right)^2 + 4 - 2\frac{a-\gamma}{\sqrt{zt}} > 2\frac{ah-\gamma}{\sqrt{zt}} - 2\frac{a-\gamma}{\sqrt{zt}} &\Rightarrow \left(\frac{a-\gamma}{2\sqrt{zt}} - 2\right)^2 > \frac{2a}{\sqrt{zt}}(h-1) \end{aligned}$$

which holds given $h \in (0, 1)$.

Using (3.7) we can check that $\mu^* < 1$ holds

$$\begin{aligned} \frac{a-\gamma}{2\sqrt{zt}} - \sqrt{\left(\frac{a-\gamma}{2\sqrt{zt}}\right)^2 - 4\left(\frac{ah-\gamma}{2\sqrt{zt}} - 1\right)} &< 2 \Rightarrow \\ \frac{a-\gamma}{2\sqrt{zt}} - 2 &< \sqrt{\left(\frac{a-\gamma}{2\sqrt{zt}}\right)^2 - 4\left(\frac{ah-\gamma}{2\sqrt{zt}} - 1\right)} \Rightarrow \\ \left(\frac{a-\gamma}{2\sqrt{zt}}\right)^2 - \frac{2(a-\gamma)}{\sqrt{zt}} + 4 &< \left(\frac{a-\gamma}{2\sqrt{zt}}\right)^2 - \frac{2(ah-\gamma)}{\sqrt{zt}} + 4 \Rightarrow \\ ah - \gamma &< a - \gamma \Rightarrow h < 1 \end{aligned}$$

Given the above and using (3.7), the threshold value m^* is equal to

$$m^* = (\mu^*)^2 = \left\{ \frac{\frac{a-\gamma}{2\sqrt{zt}} - \sqrt{\left(\frac{a-\gamma}{2\sqrt{zt}}\right)^2 - 4\left(\frac{ah-\gamma}{2\sqrt{zt}} - 1\right)}}{2} \right\}^2$$

and thus for $\hat{\delta} > h$ to hold, then $m \in (m^*, 1)$.

Recall now that the government sets an environmental tax; thus, it is interesting to analyse the effect of the tax on the threshold value $\hat{\delta}$.

Proposition 3.1. *A higher environmental tax makes the scenario of the EG conflicting with the firm more likely.*

Proof. It is easily shown that an increase in the tax rate increases the critical value of δ , $\hat{\delta}$, below which the EG chooses to conflict with the firm:

$$\frac{\partial \hat{\delta}}{\partial t} = \frac{-2m\sqrt{z}\frac{1}{2\sqrt{t}} + 2\sqrt{z}\frac{1}{2\sqrt{t}}}{a} = \frac{(1-m)\sqrt{\frac{z}{t}}}{a} > 0$$

since $m < 1$. □

Proposition 3.1 presents a result according to which higher tax will move $\hat{\delta}$ to the right making the interval $[h, \hat{\delta}]$ bigger so that the event of conflict is now more likely to happen. The intuition here lies in the environmentalists' objective. The group cares

about the environment and in particular emissions. As we will see, when taxation is increasing, total emissions under conflict fall at a higher rate compared to the decrease in emissions under collaboration. Therefore, the group will be more likely to decide to conflict with the firm since such an action will imply less pollution. To show this, recall that total emissions are a product of emission intensity and production. Let us analyse the effect of tax on emission intensity and output separately.

By taking the derivative of emission intensity under conflict and under collaboration with respect to the tax rate we get

$$\frac{\partial e_{conf}}{\partial t} = -\frac{\sqrt{z}}{2\sqrt{t}}, \quad \frac{\partial e_{coll}}{\partial t} = -\frac{\sqrt{zm}}{2\sqrt{t}}$$

and we can see that $\frac{\partial e_{conf}}{\partial t} > \frac{\partial e_{coll}}{\partial t}$ in absolute terms since $m < 1$, implying that the effect of an increase in the tax rate on emission intensity will be bigger under conflict. Similarly, for the quantities we obtain

$$\frac{\partial q_{conf}}{\partial t} = -\frac{z}{t^2}, \quad \frac{\partial q_{coll}}{\partial t} = -\frac{zm}{t^2}$$

and we can also see that $\frac{\partial q_{conf}}{\partial t} > \frac{\partial q_{coll}}{\partial t}$ in absolute terms since $m < 1$ meaning that the effect of an increase in the tax rate on output is stronger under conflict.

As discussed earlier in subsection 3.2.2, we have already seen that production, emission intensity and total emissions are negatively affected by an increase in the tax rate. Now, the above calculations show that the decrease in production, emission intensity and total emissions is bigger under conflict than collaboration. In particular, the effect of the tax on emission intensity under conflict is stronger since under collaboration, the technology chosen by the firm is already greener due to the alliance with the EG and thus, the effect of taxation in this case is weaker. The effect of the tax on output works towards the same direction namely production is decreasing more under conflict and hence total emissions are falling at a higher rate when the environmentalists clash with the firm. In other words, following a

given increase in t the decrease in total emissions under conflict is more pronounced. Therefore, a higher tax is more effective under the conflict case.

It is also worth noting that Proposition 3.1 identifies a previously unexplored, possibly adverse effect of public policy on environmental quality. Particularly, a more stringent environmental policy increases the likelihood that the environmentalists will not collaborate with the firm –an effect that not only mitigates the desirable impact of the pollution tax on emission intensity but also leads to lower output.

3.2.4 Social Welfare

We can now define the social welfare function as the sum of consumer and producer surpluses and tax revenues minus the negative externality from pollution under each case. More specifically, consumer surplus is calculated as

$$CS_i = \int_h^1 \left[\frac{(a^i - \gamma - 2\sqrt{z^i t})^2}{2} \right] f(\delta) d\delta,$$

the producer surplus as the firm's profits

$$\Pi_i = \int_h^1 \left[\frac{(a^i - \gamma - 2\sqrt{z^i t})^2}{4} \right] f(\delta) d\delta,$$

tax revenues as

$$te_i q_i = \int_h^1 \left[t \frac{a^i - \gamma - 2\sqrt{z^i t}}{2} \sqrt{\frac{z^i}{t}} \right] f(\delta) d\delta$$

and the negative externality from pollution as the total emissions⁷

$$e_i q_i = \int_h^1 \left[\frac{a^i - \gamma - 2\sqrt{z^i t}}{2} \sqrt{\frac{z^i}{t}} \right] f(\delta) d\delta$$

where $f(\delta) = \frac{1}{1-h}$.

At this point, it is important to note that the government is considered as being

⁷I assume linear damage from emissions. One interpretation for this can be a political economy interpretation where Social Welfare is a linear combination of the preferences of the players.

composed by politicians who care about the perceived welfare of citizens and this could be for electoral reasons. So, by weighting the perceived consumer surplus, profits, the environmental group's loss and the tax revenues in the government's objective function by ϕ_1, ϕ_2, ϕ_3 and ϕ_4 respectively, where $\phi_4 = \phi_1$ ⁸ and the weights add up to 1 i.e., $2\phi_1 + \phi_2 + \phi_3 = 1 \Rightarrow \phi_3 = 1 - 2\phi_1 - \phi_2$, we represent the “ideological” inclination of the government (or the government's perceived relative importance of the four arguments for re-election). This also justifies why the government will not directly campaign against pollution or will directly help the firm to implement greener technologies; this is a role already associated with the presence of the EG. Therefore, the Social Welfare function that the government will maximise can be written as:

$$\begin{aligned}
SW &= \underbrace{\int_h^{\delta} [\phi_1(CS_{conf} + te_{conf}q_{conf}) + \phi_2\Pi_{conf} - (1 - 2\phi_1 - \phi_2)e_{conf}q_{conf}]f(\delta)d\delta}_{\text{SW under conflict}} \\
&\quad + \underbrace{\int_{\hat{\delta}}^1 [\phi_1(CS_{coll} + te_{coll}q_{coll}) + \phi_2\Pi_{coll} - (1 - 2\phi_1 - \phi_2)e_{coll}q_{coll}]f(\delta)d\delta}_{\text{SW under collaboration}} \\
\Rightarrow SW &= \int_h^{\delta} \left[\phi_1 \left(\frac{q_{conf}^2}{2} + te_{conf}q_{conf} \right) + \phi_2 q_{conf}^2 - (1 - 2\phi_1 - \phi_2)e_{conf}q_{conf} \right] f(\delta) d\delta \\
&\quad + \int_{\hat{\delta}}^1 \left[\phi_1 \left(\frac{q_{coll}^2}{2} + te_{coll}q_{coll} \right) + \phi_2 q_{coll}^2 - (1 - 2\phi_1 - \phi_2)e_{coll}q_{coll} \right] f(\delta) d\delta \quad (3.8)
\end{aligned}$$

⁸For simplicity, I abstract from income effects in the consumer's demand for the good since they would complicate the analysis without providing significant new insights on the main effects I focus. Thus, I assume that tax revenues are entirely returned to consumers as a lump-sum subsidy, namely their weight in the welfare function will be equal to the weight given the consumer surplus realised in the market under consideration, $\phi_4 = \phi_1$. It should be noted that this model is not a general equilibrium one; I just consider the positive and normative analysis of a monopolised market with environmental issues. Therefore, I assume standard quasi-linear preferences in the good under consideration and income which is a typical common specification of partial equilibrium models.

$$\begin{aligned}
&= \int_h^{\hat{\delta}} \left[\phi_1 \left(\frac{(a\delta - \gamma - 2\sqrt{zt})^2}{2} + \frac{a\delta - \gamma - 2\sqrt{zt}}{2} \sqrt{\frac{z}{t}} \right) + \phi_2 \frac{(a\delta - \gamma - 2\sqrt{zt})^2}{4} \right. \\
&\quad \left. - (1 - 2\phi_1 - \phi_2) \frac{a\delta - \gamma - 2\sqrt{zt}}{2} \sqrt{\frac{z}{t}} \right] f(\delta) d\delta \\
&+ \int_{\hat{\delta}}^1 \left[\phi_1 \left(\frac{(a - \gamma - 2\sqrt{zmt})^2}{2} + \frac{a - \gamma - 2\sqrt{zmt}}{2} \sqrt{\frac{zm}{t}} \right) + \phi_2 \frac{(a - \gamma - 2\sqrt{zmt})^2}{4} \right. \\
&\quad \left. - (1 - \phi_1 - \phi_2) \frac{a - \gamma - 2\sqrt{zmt}}{2} \sqrt{\frac{zm}{t}} \right] f(\delta) d\delta.
\end{aligned}$$

Hence,

$$\begin{aligned}
SW &= \frac{1}{1-h} \left\{ \frac{1}{12} a^2 \left(\frac{1}{2} \phi_1 + \phi_2 \right) (\hat{\delta}^3 - h^3) \right. \\
&- \frac{1}{4} a \left(\frac{1}{2} \phi_1 \eta + \phi_2 \eta + (1 - 2\phi_1 - \phi_2) \frac{\sqrt{z}}{\sqrt{t}} - \phi_1 \sqrt{zt} \right) (\hat{\delta}^2 - h^2) + \frac{1}{2} \left(\phi_1 \left(\frac{\eta}{2} \right)^2 \right. \\
&\quad \left. + \frac{1}{2} \phi_2 \eta^2 + (1 - 2\phi_1 - \phi_2) \frac{\eta \sqrt{z}}{\sqrt{t}} - \phi_1 \eta \sqrt{zt} \right) (\hat{\delta} - h) \\
&\quad \left. + \frac{1}{2} \left(\phi_1 \left(\frac{a - \gamma - 2\sqrt{zmt}}{2} \right)^2 + \frac{1}{2} \phi_2 (a - \gamma - 2\sqrt{zmt})^2 \right. \right. \\
&\quad \left. \left. - (1 - 2\phi_1 - \phi_2) \frac{(a - \gamma - 2\sqrt{zmt}) \sqrt{zm}}{\sqrt{t}} + \phi_1 \sqrt{zmt} (a - \gamma - 2\sqrt{zmt}) \right) (1 - \hat{\delta}) \right\}
\end{aligned}$$

where $\eta = \gamma + 2\sqrt{zt}$.

We know how the function behaves in the two extreme cases; for the minimum value of tax, i.e., $t = 0$ and for the maximum value of tax which in this case is $t = \frac{(ah-\gamma)^2}{16z}$. The SW consists of the consumer surplus and the profits subtracting the negative externality from pollution, so in the former case we can see that $e \rightarrow \infty$ and thus $SW \rightarrow -\infty$ and in the latter case, $q = 0$, $e = 0$ and $SW = 0$. To obtain explicitly the optimal tax rate that maximises the Social Welfare function we should set $\frac{\partial(SW)}{\partial t} = 0$. However, it is not possible to find a closed-form solution for t in this setting.

3.2.5 Pure conflict vs conflict or collaboration

Due to the complexity of this problem, I undertake numerical examples to explore the effect of tax rate on Social Welfare starting with the following parameter values $a = 100$, $\gamma = 10$, $h = 0.4$, $m = 0.7$, $z = 20$ and $\phi_1 = \phi_2 = \phi_3 = \phi_4 = 0.25$ (see the shaded rows in the tables below). Let us begin by introducing a benchmark case where the only option for the group is to conflict with the firm (referred to as *first scenario*); in other words environmentalists only act against the firm, i.e., the scenario commonly presented by scholars. In this case,

$$\begin{aligned}
SW_{firstscenario} &= \int_h^1 [\phi_1(CS_{conf} + te_{conf}q_{conf}) + \phi_2\Pi_{conf} - (1 - 2\phi_1 - \phi_2)e_{conf}q_{conf}]f(\delta)d\delta \\
&= \int_h^1 [\phi_1\left(\frac{q_{conf}^2}{2} + te_{conf}q_{conf}\right) + \phi_2q_{conf}^2 - (1 - 2\phi_1 - \phi_2)e_{conf}q_{conf}]f(\delta)d\delta \\
&= \int_h^1 \left[\phi_1\left(\frac{(a\delta - \gamma - 2\sqrt{zt})^2}{2} + \frac{a\delta - \gamma - 2\sqrt{zt}}{2}\sqrt{\frac{z}{t}}\right) + \phi_2\frac{(a\delta - \gamma - 2\sqrt{zt})^2}{4} \right. \\
&\quad \left. - (1 - 2\phi_1 - \phi_2)\frac{a\delta - \gamma - 2\sqrt{zt}}{2}\sqrt{\frac{z}{t}} \right] f(\delta)d\delta.
\end{aligned}$$

This is then compared with the scenario which is presented in this model i.e., having the environmentalists facing two options, to either join forces with the firm or clash with it (referred to as *second scenario*). In such case, the SW function is as in Eq. (3.8). For these two scenarios, I calculate the optimal tax rate (t^* and t^{**} respectively) for different values of the parameters. Note that the numbers in parentheses denote the corresponding Social Welfare level in each case.

All of the following tables show that optimal tax rate in the first scenario is higher than in the second one ($t^* > t^{**}$) indicating that a more stringent environmental policy is needed when the only strategy for the environmentalists is to conflict with the firm or, in other words, that collaboration and a more stringent policy are substitutes. This result is in line with Proposition 3.1 since higher taxation is in favour of having conflict between the group and the firm. Thus, in the case in which

the group faces the option to either cooperate or clash with the firm, the optimal policy should be less stringent and therefore result in higher consumer surplus due to the smaller decrease of output relative to the first scenario (conflict only).

Table 3.1: Optimal tax for different values of z

Parameters	Optimal Tax for $SW_{firstscenario}$	Optimal Tax for $SW_{secondscenario}$
$a = 100, \mathbf{z=10}$, $\gamma = 10, \phi_1 = 0.25$, $\phi_2 = 0.25, m = 0.7$, $h = 0.4$	$t^* = 0.520$ (302)	$t^{**} = 0.450$ (327)
$a = 100, \mathbf{z=20}$, $\gamma = 10, \phi_1 = 0.25$, $\phi_2 = 0.25, m = 0.7$, $h = 0.4$	$t^* = 0.529$ (277)	$t^{**} = 0.458$ (301)
$a = 100, \mathbf{z=30}$, $\gamma = 10, \phi_1 = 0.25$, $\phi_2 = 0.25, m = 0.7$, $h = 0.4$	$t^* = 0.536$ (259)	$t^{**} = 0.465$ (282)

Table 3.1 shows the optimal tax rate under these two scenarios while changing the values for the cost of the greener technology (z). In both cases, it is increasing in z indicating that when the cost of the cleaner technology is higher the optimal tax rate is increased to still provide incentives to the firm to employ a cleaner technology. This holds for both scenarios since, regardless of whether there is a possibility of collaboration with the group or not, an increase in the cost for adopting a less polluting technology unaccompanied by an increase in the tax would discourage the firm from incurring that higher cost.

Table 3.2: Optimal tax for different values of a

Parameters	Optimal Tax for $SW_{firstscenario}$	Optimal Tax for $SW_{secondscenario}$
a=50 , $z = 20$, $\gamma = 10, \phi_1 = 0.25$, $\phi_2 = 0.25, m = 0.7$, $h = 0.4$	$t^* = 0.579$ (32)	$t^{**} = 0.507$ (36)
a=100 , $z = 20$, $\gamma = 10, \phi_1 = 0.25$, $\phi_2 = 0.25, m = 0.7$, $h = 0.4$	$t^* = 0.529$ (277)	$t^{**} = 0.458$ (301)
a=150 , $z = 20$, $\gamma = 10, \phi_1 = 0.25$, $\phi_2 = 0.25, m = 0.7$, $h = 0.4$	$t^* = 0.518$ (765)	$t^{**} = 0.447$ (831)

As table 3.2 shows, having a higher optimal tax rate for the pure conflict case (first scenario) relative to the second scenario also holds for different values of the demand parameter a . It is interesting to see that, for higher values of a , the optimal tax rate is decreasing in both cases. This may seem counter-intuitive, however it can be explained when taking into account the effect of a in $\hat{\delta}$. In particular, using Eq. (3.5) and taking the derivative of $\hat{\delta}$ with respect to a , we obtain

$$\begin{aligned} \frac{\partial \hat{\delta}}{\partial a} &= \frac{a\sqrt{m} - (a\sqrt{m} - \gamma\sqrt{m} - 2\sqrt{z}tm + \gamma + 2\sqrt{z}t)}{a^2} \\ &= \frac{(\gamma + 2\sqrt{z}mt)\sqrt{m} - (\gamma + 2\sqrt{z}t)}{a^2} < 0 \end{aligned}$$

since $m \in (0, 1)$. Therefore, an increase in a will decrease $\hat{\delta}$ in which case conflict is less likely to happen and thus, it is accompanied by lower taxation.

Table 3.3: Optimal tax for different values of h

Parameters	Optimal Tax for $SW_{firstscenario}$	Optimal Tax for $SW_{secondscenario}$
$a = 100, z = 20,$ $\gamma = 10, \phi_1 = 0.25,$ $\phi_2 = 0.25, m = 0.7,$ $h=0.3$	$t^* = 0.532$ (241)	$t^{**} = 0.465$ (262)
$a = 100, z = 20,$ $\gamma = 10, \phi_1 = 0.25,$ $\phi_2 = 0.25, m = 0.7,$ $h=0.4$	$t^* = 0.529$ (277)	$t^{**} = 0.458$ (301)
$a = 100, z = 20,$ $\gamma = 10, \phi_1 = 0.25,$ $\phi_2 = 0.25, m = 0.7,$ $h=0.5$	$t^* = 0.526$ (319)	$t^{**} = 0.450$ (348)
$a = 100, z = 20,$ $\gamma = 10, \phi_1 = 0.25,$ $\phi_2 = 0.25, m = 0.7,$ $h=0.6$	$t^* = 0.524$ (367)	$t^{**} = 0.438$ (404)

Making the range of the values that δ can take larger, we can see that it reduces the optimal tax rate in both scenarios (see Table 3.3). In other words, a lower h shrinks more the demand and thus a less stringent environmental policy is required and follows the same reasoning as the impact of the changes in a on the optimal tax. Still, tax under pure conflict is higher than the case where both collaboration and conflict can be EG's strategy.

Table 3.4: Optimal tax for different values of m

Parameters	Optimal Tax for $SW_{firstscenario}$	Optimal Tax for $SW_{secondscenario}$
$a = 100, z = 20,$ $\gamma = 10, \phi_1 = 0.25,$ $\phi_2 = 0.25, \mathbf{m=0.6},$ $h = 0.4$	$t^* = 0.529$ (277)	$t^{**} = 0.412$ (323)
$a = 100, z = 20,$ $\gamma = 10, \phi_1 = 0.25,$ $\phi_2 = 0.25, \mathbf{m=0.7},$ $h = 0.4$	$t^* = 0.529$ (277)	$t^{**} = 0.458$ (301)
$a = 100, z = 20,$ $\gamma = 10, \phi_1 = 0.25,$ $\phi_2 = 0.25, \mathbf{m=0.8},$ $h = 0.4$	$t^* = 0.529$ (277)	$t^{**} = 0.496$ (287)
$a = 100, z = 20,$ $\gamma = 10, \phi_1 = 0.25,$ $\phi_2 = 0.25, \mathbf{m=0.9},$ $h = 0.4$	$t^* = 0.529$ (277)	$t^{**} = 0.520$ (279)

Furthermore, a higher m implies that the firm is benefiting less from the cooperation with the group and as we can see, it increases the optimal tax rate in the second scenario while this tax rate is still lower than the tax rate in the pure conflict case (Table 3.4). This can be explained by considering a higher m as less transfer of the group's know-how and thus a higher optimal tax rate is required to discourage the firm from producing with a higher emission intensity. Of course, in the first scenario the changes in m do not affect the tax since there is not a possibility of cooperating with the firm.

Table 3.5: Optimal tax for different values of ϕ

Parameters	Optimal Tax for $SW_{firstscenario}$	Optimal Tax for $SW_{secondscenario}$
$a = 100, z = 20,$ $\gamma = 10, \phi_1 = \mathbf{0.25},$ $\phi_2 = \mathbf{0.25}, m = 0.7,$ $h = 0.4$	$t^* = 0.529$ (277)	$t^{**} = 0.458$ (301)
$a = 100, z = 20,$ $\gamma = 10, \phi_1 = \mathbf{0.4},$ $\phi_2 = \mathbf{0.1}, m = 0.7,$ $h = 0.4$	$t^* = 0.454$ (256)	$t^{**} = 0.365$ (275)
$a = 100, z = 20,$ $\gamma = 10, \phi_1 = \mathbf{0.1},$ $\phi_2 = \mathbf{0.7}, m = 0.7,$ $h = 0.4$	$t^* = 0.074$ (634)	$t^{**} = 0.067$ (688)
$a = 100, z = 20,$ $\gamma = 10, \phi_1 = \mathbf{0.2},$ $\phi_2 = \mathbf{0.2}, m = 0.7,$ $h = 0.4$	$t^* = 1.084$ (195)	$t^{**} = 3.600$ (70)

Finally, we can see that, in both scenarios, the optimal tax rate is higher when consumer surplus is valued more than the other arguments compared to the case where producer surplus or tax revenues are weighted more. It is however lower compared to Social Welfare being more heavily affected by pollution. Again, a more stringent environmental policy is needed under the first scenario where the group only conflicts with the firm (Table 3.5).

Various combinations of parameter values included in the tables above are also presented in Appendix V in the form of graphs. All in all, the above results indicate that a less stringent environmental policy should be implemented when the group faces an additional option of partnering with the firm relative to when the only option

is to conflict. This is can be explained given the way that the environmental tax alters the probability of conflict compared to collaboration in favour of the former. Also it is worth noting that SW (numbers in brackets in the above tables) is higher when the less stringent policy is set (second scenario).

3.3 Conclusion

The idea of environmentalists clashing with firms is not new; what is novel in recent years is the phenomenon of green alliances, the collaboration between a firm and an environmental group in developing and implementing a cleaner production technology. The former notion has already been well examined in the literature. However, to the best of my knowledge, the option of cooperation between these two players has not been modelled by scholars yet and thus this chapter signifies a first attempt towards this direction.

In particular, in this model, environmentalists can either act against the firm and the consequences of its polluting production which will reduce emissions via a contraction in demand or join forces with the firm and share their know-how which will provide incentives to the firm to employ a cleaner technology through the decrease in its cost of adoption. The group makes its decision based on which option entails less pollution and it is affected by an environmental tax set by the government. This, then, impacts firm's choices on output and emission intensity.

I have shown that higher taxes make the conflict case more likely to happen, indicating that collaboration and a more stringent environmental policy are substitutes. This sheds light to a previously unexplored, possibly adverse effect of public policy on environmental quality because it mitigates the desirable impact of the pollution tax on emission intensity since the latter is higher under conflict and leads to lower output.

I also undertake by means of numerical examples the calculation of the optimal tax that maximises Social Welfare and I find that in the case conflict is the only

option for the environmentalists the tax is higher relative to the case where the group can choose either to conflict or collaborate with the firm, implying that a less stringent environmental policy is required in the second scenario. This is due to the way that the environmental tax alters the probability of conflict compared to collaboration in favour of the former.

This analysis has a number of limitations. For instance, it would be interesting to examine a framework where the firm would not be always willing to collaborate with the group or having more than one firms in the market and explore the interactions between them, the outcome in terms of which firm will manage to collaborate with the environmentalists and the effects on pollution and welfare since attention has been restricted in the monopoly scenario in this model. Nevertheless, in any case, this chapter provides an attempt to embrace the changing landscape in the relationship between a firm and an environmental group and opens the way for future research.

Thesis Conclusion

This thesis discusses issues such as emissions leakage, corruption and green alliances with a particular interest in how they impact environmental quality.

In Chapter 1, we investigate the relationship between corruption and market entry. We find that there is a possibility of a self reinforcing cycle where corruption by decreasing the expecting operating costs in the market increases the number of firms that enter the industry while the latter provides the incentives to bureaucrats to engage in corrupt activities due to the higher expected benefits of being corrupt. This leads to multiple equilibria where both a regime with corruption and one without are possible equilibria. This analysis is utilised to understand how corruption affects environmental quality through market entry and it is shown that corruption increases not only the number of firms entering the market and thus polluting production but also the fraction of firms that undertake the “dirtier” technology.

Chapter 2 explores the effect of environmental consciousness on pollution and identifies the case of having consumers in one country caring only about domestic emissions as a reason for emissions leakage and increased pollution in the foreign country. It is also shown that the transition from local to global consciousness where these consumers now care about both domestic and global pollution as an initiative to mitigate leakage indeed diminishes pollution abroad.

Finally, Chapter 3 challenges the classical way of thinking that environmentalists always clash with firms and is the first to provide a theoretical framework where the environmental group has the option to collaborate with the firm if such an action

lowers total emissions. This relates to the empirical evidence where green alliances are becoming a popular phenomenon. In terms of policy implications, one of the main results of this analysis suggests that higher taxation makes it more likely that the group will act against the firm, indicating that collaboration and a more stringent environmental policy are substitutes. This identifies an unexplored by scholars and possibly adverse effect of public policy on environmental quality because it mitigates the desirable impact of the pollution tax on emission intensity since the latter is higher under conflict and leads to lower output.

All in all, this thesis provides insight into the aforementioned issues that impinge on environmental quality and into the resulting policy implications. At the same time, although it raises further questions that could not be addressed within the context of this thesis and which represent fruitful avenues to pursuit, it calls for a greater understanding of the recent challenges for tackling climate change, one of the most persistent concerns facing today's society.

Chapter 4

Appendix

Appendix I

The non-negativity constraint on $q_{1F}^{(1)}$ (Eq. (2.7)) requires:

$$q_{1F}^{(1)} = \frac{(a-c)(2-\theta) - 2k_F e_1}{b(4-\theta^2)} \geq 0 \Rightarrow (a-c)(2-\theta) - 2k_F e_1 \geq 0.$$

Since $\lambda = n(a-c)(2-\theta)$, then $(a-c)(2-\theta) - 2k_F e_1 \geq 0 \Rightarrow \frac{\lambda}{n} - 2k_F e_1 \geq 0 \Rightarrow \lambda - 2nk_F e_1 \geq 0$, so

$$e_1 \leq \frac{\lambda}{2nk_F}.$$

Using Eq. (2.9) and in order to avoid corner solutions, this condition becomes

$$\frac{\beta\epsilon - 4k_F\lambda}{\beta\epsilon - 8nk_F^2} < \frac{\lambda}{2nk_F} \Rightarrow \beta\epsilon 2nk_F - 8nk_F^2\lambda < \beta\epsilon\lambda - 8nk_F^2\lambda \Rightarrow \lambda > 2nk_F.$$

The above condition guarantees that $e_1^{*(1)} < 1$. Indeed,

$$\frac{\beta\epsilon - 4k_F\lambda}{\beta\epsilon - 8nk_F^2} < 1 \Rightarrow \beta\epsilon - 4k_F\lambda < \beta\epsilon - 8nk_F^2 \Rightarrow \lambda > 2nk_F.$$

Appendix II

Using equation (2.9), the stability condition (in order to have a stable equilibrium) and the second order condition for a maximum require for e_1 :

$$\left| \frac{\partial^2 \Pi_1^{(1)}}{\partial e_1^{2(1)}} \right| > \left| \frac{\partial}{\partial e_2^{(1)}} \left(\frac{\partial \Pi_1^{(1)}}{\partial e_2^{(1)}} \right) \right| \Leftrightarrow \left| \frac{8nk_F^2 - \beta\epsilon}{\epsilon} \right| > 0$$

and

$$\frac{8nk_F^2 - \beta\epsilon}{\epsilon} < 0 \Rightarrow \beta\epsilon > 8nk_F^2,$$

respectively and for e_2 :

$$\left| \frac{\partial^2 \Pi_2^{(1)}}{\partial e_2^{2(1)}} \right| > \left| \frac{\partial}{\partial e_1^{(1)}} \left(\frac{\partial \Pi_2^{(1)}}{\partial e_1^{(1)}} \right) \right| \Leftrightarrow |-\beta| > 0$$

and

$$-\beta < 0$$

respectively which holds.

For $e_1^{*(2)}$ and $e_2^{*(2)}$, the stability condition requires:

$$\frac{\partial^2 \Pi_1^{(2)}}{\partial e_1^{2(2)}} \frac{\partial^2 \Pi_2^{(2)}}{\partial e_2^{2(2)}} - \frac{\partial^2 \Pi_1^{(2)}}{\partial e_1^{(2)} \partial e_2^{(2)}} \frac{\partial^2 \Pi_2^{(2)}}{\partial e_1^{(2)} \partial e_2^{(2)}} > 0 \Leftrightarrow (\beta\epsilon - 8nk_F^2)(\beta\epsilon - 8nx_F^2) > (4n\theta k_F x_F)^2 \quad (4.1)$$

which implies that $(\beta\epsilon - 8nx_F^2)(\beta\epsilon - 4k_F\lambda) > 4n\theta k_F x_F(\beta\epsilon - 4x_F\lambda)$ for $e_1^{*(2)}$ to be positive and $(\beta\epsilon - 8nk_F^2)(\beta\epsilon - 4x_F\lambda) > 4n\theta k_F x_F(\beta\epsilon - 4k_F\lambda)$ for $e_2^{*(2)}$ to be positive.

The second order condition for a maximum implies that:

$$\frac{\partial^2 \Pi_1^{(2)}}{\partial e_1^{2(2)}} = \frac{8nk_F^2 - \beta\epsilon}{\epsilon} < 0 \Leftrightarrow \frac{\beta\epsilon - 8nk_F^2}{\epsilon} > 0$$

$$\frac{\partial^2 \Pi_2^{(2)}}{\partial e_2^{2(2)}} = \frac{8nx_F^2 - \beta\epsilon}{\epsilon} < 0 \Leftrightarrow \frac{\beta\epsilon - 8nx_F^2}{\epsilon} > 0$$

Thus, the following inequalities should hold:

$$\beta\epsilon > 8nk_F^2 \quad \text{and} \quad \beta\epsilon > 8nx_F^2. \quad (4.2)$$

Appendix III

Proof to Proposition 2.1. By using Eq. (2.6) along with (2.9), it is easy to see that, for firm 1:

$$\Delta e_1' = e_1^{*(1)} - e_1^{*(0)} = \frac{\beta\epsilon - 4k_F\lambda}{\beta\epsilon - 8nk_F^2} - 1 < 0$$

since $e_1^{*(1)} < 1^1$ and by using Eq. (2.9) & (2.13), I get:

$$\Delta e_1'' = e_1^{(2)} - e_1^{*(1)} = \frac{\beta\epsilon - 4k_F\lambda - 4n\theta k_F x_F e_2}{\beta\epsilon - 8nk_F^2} - \frac{\beta\epsilon - 4k_F\lambda}{\beta\epsilon - 8nk_F^2} = -\frac{4n\theta k_F x_F e_2}{\beta\epsilon - 8nk_F^2} < 0$$

since $\beta\epsilon - 8nk_F^2 > 0$ (Eq. 4.2). I used the reaction function of $e_1^{(2)}$ since it is more straightforward to show that the difference in firm's 1 emission rate is positive since $e_2 > 0$. Similarly for firm 2,

$$\Delta e_2' = e_2^{*(1)} - e_2^{(0)} = 1 - 1 = 0.$$

and

$$\Delta e_2'' = e_2^{*(2)} - e_2^{*(1)} = \frac{(\beta\epsilon - 8nk_F^2)(\beta\epsilon - 4x_F\lambda) - 4n\theta k_F x_F (\beta\epsilon - 4k_F\lambda)}{(\beta\epsilon - 8nk_F^2)(\beta\epsilon - 8nx_F^2) - (4n\theta k_F x_F)^2} - 1 < 0.$$

□

¹ $e_i = [0, 1]$

Proof to Proposition 2.2. Regarding the changes in output of good 1, I have from Eq. (2.3) and (2.10):

$$\begin{aligned}\Delta Q_1' &= Q_1^{*(1)} - Q_1^{*(0)} = \\ &= \frac{(a-c)(2-\theta) - \frac{2nk_F(\beta\epsilon - 4k_F\lambda)}{\beta\epsilon - 8nk_F^2}}{b(4-\theta^2)} - \frac{(a-c)(2-\theta)}{b(4-\theta^2)} = -\frac{2nk_F(\beta\epsilon - 4k_F\lambda)}{\beta\epsilon - 8nk_F^2} < 0\end{aligned}$$

since $(\beta\epsilon - 4k_F\lambda) > 0$ holds.

By using Eq. (2.10) and (2.14) I have:

$$\Delta Q_1'' = Q_1^{*(2)} - Q_1^{*(1)} = \frac{nx_F\theta \left[\overbrace{(\beta\epsilon - 8nk_F^2)(\beta\epsilon - 4x_F\lambda) - 4n\theta k_F x_F (\beta\epsilon - 4k_F\lambda)}^+ \right]}{b(\beta\epsilon - 8k_F^2 n)(4 - \theta^2) \left[\underbrace{(\beta\epsilon - 8nk_F^2)(\beta\epsilon - 8nx_F^2) - (4n\theta k_F x_F)^2}_+ \right]} > 0$$

since it is shown that $nx_F\theta > 0$, $(\beta\epsilon - 8nk_F^2)(\beta\epsilon - 4x_F\lambda) - 4n\theta k_F x_F (\beta\epsilon - 4k_F\lambda) > 0$ and $(\beta\epsilon - 8nk_F^2)(\beta\epsilon - 8nx_F^2) - (4n\theta k_F x_F)^2 > 0$ (Eq. 4.1).

For good 2, from Eq. (2.4) and (2.11):

$$\begin{aligned}\Delta Q_2' &= Q_2^{*(1)} - Q_2^{*(0)} = \\ &= \frac{(a-c)(2-\theta) + \frac{\theta nk_F(\beta\epsilon - 4k_F\lambda)}{\beta\epsilon - 8nk_F^2}}{b(4-\theta^2)} - \frac{(a-c)(2-\theta)}{b(4-\theta^2)} = \frac{\theta nk_F(\beta\epsilon - 4k_F\lambda)}{\beta\epsilon - 8nk_F^2} > 0\end{aligned}$$

and from Eq. (2.11) and (2.15):

$$\begin{aligned}\Delta Q_2'' &= Q_2^{*(2)} - Q_2^{*(1)} = \\ &= -\frac{2nx_F \left[\overbrace{(\beta\epsilon - 8nk_F^2 + 2n\theta^2 k_F^2)}^+ \right] \left[\overbrace{(\beta\epsilon - 8nk_F^2)(\beta\epsilon - 4x_F\lambda) - 4n\theta k_F x_F (\beta\epsilon - 4k_F\lambda)}^+ \right]}{b(\beta\epsilon - 8k_F^2 n)(4 - \theta^2) \left[\underbrace{(\beta\epsilon - 8nk_F^2)(\beta\epsilon - 8nx_F^2) - (4n\theta k_F x_F)^2}_+ \right]} < 0\end{aligned}$$

since we know that $2nx_F(\beta\epsilon - 8nk_F^2 + 2n\theta^2 k_F^2) > 0$ as it is proven that $\beta\epsilon - 8nk_F^2 > 0$, also $(\beta\epsilon - 8nk_F^2)(\beta\epsilon - 4x_F\lambda) - 4n\theta k_F x_F (\beta\epsilon - 4k_F\lambda) > 0$ and $(\beta\epsilon - 8nk_F^2)(\beta\epsilon - 8nx_F^2) - (4n\theta k_F x_F)^2 > 0$

$$(4n\theta k_F x_F)^2 > 0 \text{ (Eq. 4.1).} \quad \square$$

Proof to Proposition 2.3. For $k_F > 0$ (case I), according to Proposition 2.1 we can easily see that, in total, emission rates are lowered ($\Delta e'_1 < 0$ & $\Delta e'_2 = 0$) and from Eq. (2.5) compared with Eq. (2.12) we get

$$\Delta(Q_1 + Q_2) = (Q_1^{(1)} + Q_2^{(1)}) - (Q_1^{(0)} + Q_2^{(0)}) = -\frac{\overbrace{nk_F(\beta\epsilon - 4k_F\lambda)}^+}{\underbrace{b(\beta\epsilon - 8nk_F^2)}_+ \underbrace{(2 + \theta)}_+} < 0$$

which implies that total output is lowered. Hence, aggregate pollution is lower than the benchmark case. □

Appendix IV

Assumption 1. This assumption implies that, for given demand conditions, collaboration always reduces total emissions. Formally,

$$\frac{a^i - \gamma - 2\sqrt{zmt}}{2} \sqrt{\frac{zm}{t}} < \frac{a^i - \gamma - 2\sqrt{zt}}{2} \sqrt{\frac{z}{t}} \Rightarrow$$

$$(a^i - \gamma - 2\sqrt{zmt})\sqrt{m} < a^i - \gamma - 2\sqrt{zt}.$$

The LHS of the inequality is a function of m . In particular,

$$\begin{aligned} \frac{\partial(LHS)}{\partial m} &= \frac{1}{2\sqrt{m}}(a^i - \gamma - 2\sqrt{zmt}) - \frac{1}{2\sqrt{m}}2\sqrt{zt}\sqrt{m} \\ &= \frac{1}{2\sqrt{m}}(a^i - \gamma - 2\sqrt{zmt}) - \sqrt{zt} \\ &= \frac{1}{2\sqrt{m}}(a^i - \gamma - 2\sqrt{zmt}) - \frac{2\sqrt{zmt}}{2\sqrt{m}} = \frac{1}{2\sqrt{m}}(a^i - \gamma - 4\sqrt{zmt}). \end{aligned}$$

This expression is decreasing in m . As long as $a^i - \gamma > 4\sqrt{zt} \forall a^i$ then $\frac{\partial(LHS)}{\partial m} > 0 \forall m \in (0, 1)$. Thus, the inequality $(a^i - \gamma - 2\sqrt{zmt})\sqrt{m} < a^i - \gamma - 2\sqrt{zt}$ holds $\forall m \in (0, 1)$. Note that assuming $ah - \gamma > 4\sqrt{zt}$ is sufficient for the non-negativity constraint on output $ah - \gamma \geq 2\sqrt{zt}$ (Eq. 3.3) to hold in order avoid a corner solution.

Appendix V

The following graphs are depicting SW with respect to tax when conflict is the only strategy for the group (first scenario) and when the environmentalists have the option to either conflict or collaborate with the firm (second scenario).

For $a = 100$, $\gamma = 10$, $h = 0.4$, $m = 0.7$, $z = 20$ and $\phi_1 = \phi_2 = \phi_3 = \phi_4 = 0.25$ (baseline):

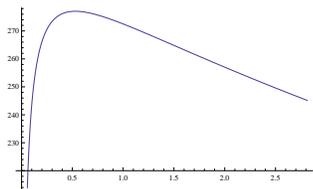


Figure 4.1: First scenario - baseline

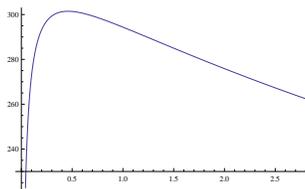


Figure 4.2: Second scenario - baseline

For $a = 100$, $\gamma = 10$, $h = 0.4$, $m = 0.7$, $z=10$ and $\phi_1 = \phi_2 = \phi_3 = \phi_4 = 0.25$ (corresponding to Table 3.1):

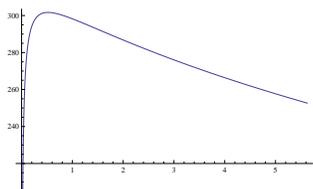


Figure 4.3: First scenario (z)

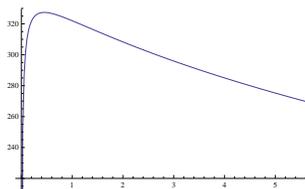


Figure 4.4: Second scenario (z)

For $\mathbf{a}=150$, $\gamma = 10$, $h = 0.4$, $m = 0.7$, $z = 20$ and $\phi_1 = \phi_2 = \phi_3 = \phi_4 = 0.25$ (corresponding to Table 3.2):

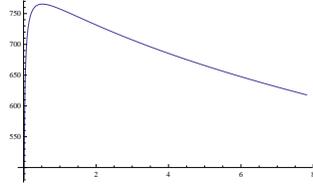


Figure 4.5: First scenario (a)

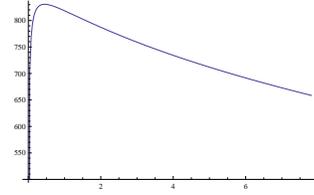


Figure 4.6: Second scenario (a)

For $a = 100$, $\gamma = 10$, $h = 0.4$, $m = 0.7$, $z = 20$ and $\phi_1 = \mathbf{0.4}$, $\phi_2 = 0.1$, $\phi_3 = 0.1$, $\phi_4 = \phi_1 = 0.4$ (corresponding to Table 3.5):

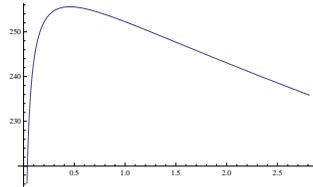


Figure 4.7: First scenario (ϕ_1)

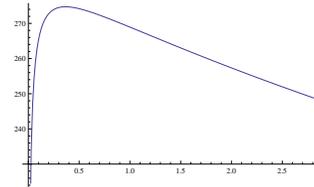


Figure 4.8: Second scenario (ϕ_1)

For $a = 100$, $\gamma = 10$, $h = 0.4$, $m = 0.7$, $z = 20$ and $\phi_1 = 0.1$, $\phi_2 = \mathbf{0.7}$, $\phi_3 = 0.1$, $\phi_4 = \phi_1 = 0.1$ (corresponding to Table 3.5):

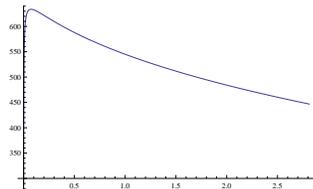


Figure 4.9: First scenario (ϕ_2)

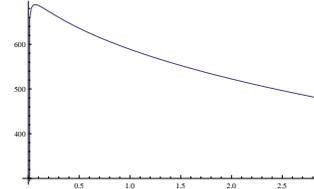


Figure 4.10: Second scenario (ϕ_2)

For $a = 100$, $\gamma = 10$, $h = 0.4$, $m = 0.7$, $z = 20$ and $\phi_1 = 0.2$, $\phi_2 = 0.2$, $\phi_3 = \mathbf{0.4}$, $\phi_4 = \phi_1 = 0.2$ (corresponding to Table 3.5):

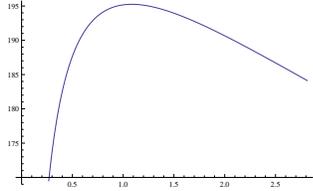


Figure 4.11: First scenario (ϕ_3)

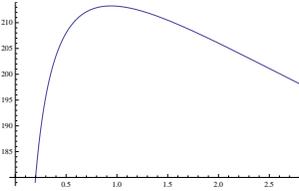


Figure 4.12: Second scenario (ϕ_3)

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