

Essays on Environmental Economics:
Environmental Compliance, Policy and Governance

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Chapter 1

Introduction

Despite an increasing environmental awareness of citizens worldwide, active measures and cooperation endeavored, and more environmental protection legislations enacted in all the countries, more environmental problems arise. The environmental degradation, in terms of both scale and gravity, has become a major obstacle for the long-term economic development.

“The right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations”, written in Agenda 21 which is an active plan on sustainable development initiated by United Nations. Providing the complex nature of environmental problems, multilateral actions to be taken globally, nationally and locally are called for to achieve the goal of sustainability. Hence, the thesis expects to shed light on this issue through environmental economics and governance, which consists of policies, institutions, practices and stakeholders related to the management of the environment.

Environmental governance, considered in particular with economics, is a whole system of management encompassing roles of government, business and households at all organizational levels. Hence, my thesis tends to convey the idea of integrated environmental governance, with its three chapters focus on the governance at the international, national and firm level, respectively. Though linked by the same theme, each chapter is

self-contained and can be read independently.

In the second chapter, I investigate global environmental governance, where achieving a greener environment necessitates cooperation across countries. The chapter studies international environmental agreements, with its innovation in taking into account multiple pollutants with cross-effect and the negotiation sequence. It aims to answer, for example, does cooperating on one type of agreement facilitate later negotiations? Which countries join which agreement? And does the negotiation agenda matters in the sense of participations?

By analyzing the membership outcome in each negotiation sequence, I find that a cooperation in the first stage can facilitate later negotiations and countries are prone to cooperate on the pollutant of common concern. The model also mirrors the friction between developed countries and the developing countries, suggesting that developing and developed countries cooperate only if their environmental concerns or the abatement costs are similar.

Most importantly, except for symmetric cases, the membership outcome is different in different negotiation agenda. On one hand, this can be used by some countries to better suit their benefits, by means of proposing the preferred negotiation agenda. On the other hand, besides transfer, issue leakage, threats and multiple agreements as discussed in Carraro and Siniscalco (1998), the negotiation sequence can serve as another instrument to possibly enlarge the participations of environmental treaties.

The third chapter involves environmental governance on the national level. Specifically, I analyze when the environmental policy is predetermined, how to distribute environmental enforcement power when there are two possible levels of enforcement-run by central or local authorities. I analyze firms' compliance behavior and the optimal inspection strategy under centralized, decentralized and mixed enforcement set-up. Comparing the welfare impact, only when there is a large heterogeneity in inspection effectiveness across regions, the decentralized enforcement is preferred.

In the extension where the central authority is more concerned about the environment than the local ones due to an international pressure, I find that under some cir-

cumstances each jurisdictional level prefers the opposite as to the superior enforcement structure, which may lead to tensions and further problems between different organizational levels. Besides, a mixed enforcement with one region self-governed and the other under central regulation is studied, which causes even more strategic behaviors than the fully decentralization case.

This chapter brings the environmental federalism literature to a new perspective of environmental tasks other than policies by taking into consideration compliance problems. The implications of the essay can be generalized to international treaties, where no robust incentives are provided for countries' compliance even if they initially participated in the agreement. Since the lack of enforcement may induce environmental crisis, the future policy design should pay more attention on the national and regional institutions.

Besides cooperation worldwide and regulations by governments, environmental governance deserves more attention on the business unit, i.e., the firms. In particular, the environmental violations are documented as the most frequent form of corporate illegality (Hill et al.1992), yet few research is carried out to explore the organizational obstacles that influence the firms' environmental resource allocations. Thus in the fourth chapter, I look into the environmental governance within the firm. Trying to open the black box, this chapter studies whether and how a firm's characteristics, in particular its corporate governance, affect the environmental compliance behavior.

Besides a general deterrent effect of environmental regulation, this essay provides a novel angle in explaining the heterogeneity of corporate environmental performance. By both theoretical and empirical means, I find that the impact of firm's corporate control on the degree of environmental violation exhibits an inverse-U trend. Comparing to no significant relationship found in McKendall et.al (1999), Halme and Huse (1997), this model better captures the relation between firms' corporate structure and its environmental performance. Hence, additional to conventional expectation that an improvement of a firm's corporate governance should lessen its environmental in-compliance, the reverse effect can also take place.

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Chapter 2

International Environmental Agreements with Agenda and Interaction between Pollutants

2.1 Introduction

The 2009 Copenhagen Climate Congress has attracted intensive attention and discussion on the topic of climate change. The environment and climate change is recognized by governments, organizations, and individuals as one of the greatest challenges of the present. As is known to all, the environmental quality is considered a public good, and achieving a greener environment needs cooperation within and across countries. Efforts have already been made with new agreements being signed and this is a clear signal that countries are starting to cooperate in the shadow of a potential environmental crisis. The well-known Kyoto protocol, entered into force since 2005, aims at reducing green house gases at the global level. It has been signed by 191 countries, except that United States has not ratified it. The 1989 Montreal Protocol on Substances That Deplete the Ozone Layer, signed by 197 parties, is regarded as the most successful environmental treaty from both membership and implementation point of view. Moreover, the Convention on

Long-Range Transboundary Air Pollution (CLRTAP) has been signed only by Europe and North America, and the Stockholm Convention on Persistent Organic Pollutants are signed by almost all of the countries except US and Russia.

Every environmental agreement is signed by different parties. In environmental economics, the literature on this issue has been mostly focused on the coalition behavior for international environmental agreements (IEAs). For instance, Barrett (1994) concludes that IEAs can do little to improve on the non-cooperative outcome when the number of countries is large. Following this argument, many papers afterwards focus more on the participation behavior and the ways that may lead to enlargement of the membership. In this line, Carraro and Siniscalco (1993) analyze the benefit of transfers, Barrett (1997) discusses the effect of trade sanctions, Ecchia and Mariotti (1998) emphasize the role of international institutions, and in Botteon and Carraro (1998), they focus on the burden sharing rules in the treaties. Furthermore, Carraro and Siniscalco (1998) discusses several mechanisms such as transfer, issue leakage, threats and multiple agreements. On the contrary, Hoel and Schneider (1997) argue that the prospect of receiving a transfer for reducing one's emissions tends to reduce the incentive a country might have to commit itself to cooperation. Hoel (1997) studies the effect of a country setting a good example by unilateral reducing harmful emissions, the result turns out to be that the total emission is even higher than when both countries act selfishly. Besides, Rubio and Ulph (2007) use a dynamic model to analyze an endogenous change of membership in response to the stock pollutant.

Among previous literature, it is usually assumed that there is one pollutant, and there is one agreement. However in reality, many environmental agreements are signed in a sequential way. For example, shortly after 1989 the Montreal Protocol on Substances That Deplete the Ozone Layer was signed, countries agreed on the Framework Convention on Climate Change in 1992, which eventually evolved to become the Kyoto Protocol. So some natural questions arise, if the agreements have been discussed and signed sequentially, why have countries chosen to sign the agreements in a particular sequence? Does cooperating on one type of agreement facilitate later negotiations? And

which countries join which agreement? Does the negotiation agenda matters in the sense of participations? These questions are mainly what this paper tries to approach.

Assuming until now that countries usually negotiate agreements on each pollutant sequentially and that each pollutant is considered as one independent issue on a country's agenda, I want to study the coalition behavior of countries when pollutants are no longer independent. In fact, pollutants are indeed, correlated. And it can happen during the production process, the abatement procedures, or even in the air after the emission as argued in Legras and Zaccour (2008). In this paper, I focus on the pollutant correlations in abatement process. For example, the catalytic converter installed in the car does not only absorb the SO_x , but also some of NO_x . So far, the literature has not discussed much the case of multiple pollutants. Caplan and Silva (2005) brought forward an efficient mechanism to control correlated externalities, and the following work by Caplan (2006) compared tax and permit markets in such mechanism. Kuosmanen and Laukkanen (2009) conclude that optimal abatement may focus on a single pollutant. Silva and Zhu (2009) discuss that the cutbacks in global pollutant can yield "double dividends" for non-participating countries, and their later work in Silva and Zhu (2011) combine the trade effect in the international environmental agreements with correlated transnational pollutants.

In this paper, where pollutants are correlated, I want to analyze countries' participation decision in international environmental agreement and how the sequence of negotiation on each pollutant matters. Considering a model of two countries, they face the environmental damages caused by two pollutants. One pollutant is global, which makes each country suffer the same damage from the total emission. The other pollutant is local, and its damage has a spillover effect on the neighboring country. These two pollutants can correspond to global warming gases and air pollutions, where the links between them are analyzed extensively in EEA report (2004). The correlation between two pollutants can be positive or negative, meaning they are, either substitutes or complements, respectively. In the model, I assume that the two countries are cooperating to improve the environmental quality by means of international treaties, and negotiate

on countries' abatement obligations for each pollutant sequentially.

This paper allows for different sequences of negotiation: countries either first negotiate on the local pollutant and later on the global one or countries negotiate first on the global and later on the local pollutant. Solving the problem by backward induction, I attain the participation behavior and the corresponding abatement level on each pollutant for both countries under each sequence. The equilibrium outcome under both negotiation agendas is not the same, which verifies the expectation that the negotiation sequence does matter in countries' participation decisions.

If in the first period countries successfully reach an agreement on one pollutant, this facilitates the negotiation for the subsequent stage, compared to the case in which an agreement failed during the first round. This paper is also able to show that countries with similar concerns on a pollutant can easily reach an agreement on that pollutant, irrespective of other parameters. In addition, if countries can only be successfully cooperating on one pollutant, they sign an agreement on the issue for which concerns are more similar.

Besides, the correlation effect of pollutants plays an important role in negotiations among countries. The probability of agreement is higher when the pollutants are complements than when they are substitutes, since being complements induces savings in the abatement cost, therefore facilitating the negotiation process. Also, the spillover effect has an influence on the negotiation outcome, in the sense that the possibility of reaching cooperation is decreasing in the spillover parameter of local pollutant. For the relative abatement cost parameter for local pollutant, the closer it is to the abatement cost of global pollutant, the easier the negotiation would be.

To explain the results more clearly, three representative illustrations are presented. The first considers symmetric countries with the same concern on each pollutant, where they always cooperate. Second, if one country is generally more environmentally concerned or more developed than the other, they can reach an agreement in all stages if their concern is sufficiently similar, otherwise their cooperation fails. This is the situation that mirrors the friction between developed countries and the developing countries

group in international environmental agreement negotiations, due to the huge gap in both technological efficiency and concern over pollutants. The third case corresponds to asymmetric countries where they generally regard the environment the same, but one is more concerned about the local or national environment. One conclusion is that, when pollutants are complements, the negotiation agenda that starts with the local pollutant achieves a larger membership than the other sequence. Hence, to ensure full participation, it is better for the countries to negotiate first on the local pollutant and then on the global one, or say, to negotiate starting from an easier issue.

The rest of the paper is organized as follows. In the next section, I describe the model and assumptions. Section 2.3 solves the model for one specific negotiation agenda, leaving the equilibrium of the other sequence to be solved in section 2.4. It is followed by section 2.5 where the comparisons of both negotiation sequences are presented. The last section concludes.

2.2 The Model

2.2.1 Basic setting

There are two neighboring countries, or two unions, indexed by subscript i , $i=1,2$. In each country, multiple pollutions are emitted from various production processes. To better account for different characteristics of emissions, I assume that there are two pollutants. One pollutant is a global pollutant such as carbon dioxide causing global warming, and the other is a local pollutant, for example nitrogen oxide NO_x or other air pollutants. The main difference between these two pollutants lies in the externalities they create. For the global pollutant, each country suffers the same from total emissions of both countries, while the local pollutant has only a partial effect on the neighboring country. This spillover effect may be different depending on countries' relative location, as well as other nature conditions.

Each country is concerned about the environmental quality. To improve it, they make efforts on pollution reductions. The abatement levels for both global and local abatement are denoted as A_i and a_i ($A_i > 0$, $a_i > 0$) for country i , $i = 1, 2$. The abatement of pollutants occurs at a cost. In line with Moslener and Requate (2007), I assume this cost function to be convex and to have the following form (more about joint abatement cost can be referred to Beavis and Walker, 1979):

$$C(A_i, a_i) = A_i^2 + \eta a_i^2 + \sigma A_i a_i \quad i = 1, 2$$

It represents the total cost of abating the global pollutant (A_i^2), abating the local pollutant (ηa_i^2) and the cost correlation between them ($\sigma A_i a_i$). I assume $0 < \eta < 1$, indicating that abating a local pollutant is less costly than abating the global one. This is in accordance with the stylized fact of the current technologies, for example, the cost of carbon capture for abating carbon dioxide is more than ten times the abatement cost of sulfur oxide SO_x .

Besides, I assume a correlation between two pollutants, since the abating process of a target pollutant is very likely to have an effect on another pollutant. Specifically, the correlation makes the pollutants either substitutes or complements. When $\sigma > 0$, abating one pollutant increases the cost of abating the other. An example of this correlation can be found in abatement technologies such as carbon capture, where the carbon dioxide is removed but other air pollutions SO_x and NO_x increase by 30% due to the additional energy consumption. This tends to increase the total abatement cost, and the two pollutants are said to be substitutes. Similarly, when $\sigma < 0$, abating one pollutant absorbs the other at the same time and decreases the total abatement cost, making the pollutants as complements. No matter which kind of correlation there is, the correlation effect in general can not be large, hence I impose another assumption $4\eta - \sigma^2 > 0$, to avoid an unrealistic large correlation between two pollutants and unrealistic equilibrium outcomes.

Assumption $\sigma^2 < 4\eta$, suggests that the correlation effect between two pollutants is not too large.

With the use of abatement technologies countries can benefit from the improvement of the environmental quality. I define the country i 's revenue function as:

$$\lambda_i(A_i + A_j) + \epsilon_i(a_i + \gamma a_j) \quad i = 1, 2$$

In this expression, γ measures the spillover effect to the neighboring country, which is assumed to be symmetric. Besides, λ and ϵ are country specific, representing the marginal revenue (or concern) for reducing the global and local pollutant, respectively. Therefore, the objective function of country i is additive of both benefit and cost function, and is given as follows:

$$W_i = \lambda_i(A_i + A_j) + \epsilon_i(a_i + \gamma a_j) - A_i^2 - \eta a_i^2 - \sigma A_i a_i \quad i = 1, 2$$

The welfare function is in line with Barrett (1997), but with an extension to multiple pollutants. From the welfare function, one can explicitly see the externalities of both pollutants. To try to deal with the public "bad", countries may want to cooperate on pollution reduction by means of international environmental treaties.

To mitigate the massive complexity and negotiation costs, at each point in time countries focus the negotiation of an agreement on one particular pollutant, as is also the case in the real world. They negotiate on the respective abatement level for each country so that it maximizes the total welfare of both countries. Without cooperation, countries choose their own abatement level strategically. I call this status quo when no agreement is signed. As often observed in some agreement failures, if the efficient abatement level makes one country worse off comparing to the status quo, it will surely drop the agreement.¹ That is also the reason why every environmental treaty is signed by different representatives of countries. Hence, it is assumed that only when both countries

¹Other possible ways of negotiation, say binding agreements, which lower the abatement obligation for some countries just to pull them in the agreement, are not considered. One reason is that a full membership can always be achieved under some forms of negotiations. In this way the agenda problem does not exist. In fact, countries cannot tolerate any cutdown of the abatement obligation for other countries.

are better off with the environmental agreement, they agree to sign it. Otherwise, they implement their own national environmental policy, disregarding externalities to other countries. This is consistent with the trade agreements, that only when the countries can be benefited from the agreement will they agree on the treaties.

In this negotiation process, I assume that no monetary transfer is being carried out. Even if the government is willing to provide monetary incentives for other country to protect the environment, raising the fund is not only complicated and costly, but also difficult due to the need of gaining the consensus of its citizens. In fact, monetary transfer is hardly observed in environmental treaties, and imposing conditions to allow transfers is unrealistic. Furthermore, once the agreement is signed, there is commitment and countries will enforce the agreement.

The timing of the game is as follows, and the sequence of negotiation is exogenous.

1. Countries negotiate on one pollutant (global pollutant A or local pollutant a), if both countries can be better off with an efficient abatement obligation, they agree to sign the environmental treaty and the abatement level for each country is settled. If it makes one country worse off, the negotiation fails and the countries don't do anything.
2. Countries negotiate on the other pollutant (a or A), if both countries choose to cooperate, they sign the agreement and decide the corresponding abatement level on that pollutant, otherwise, no measure is taken.
3. If at some of the previous stages no agreement is reached, countries decide simultaneously and strategically their abatement level of that particular pollutant.

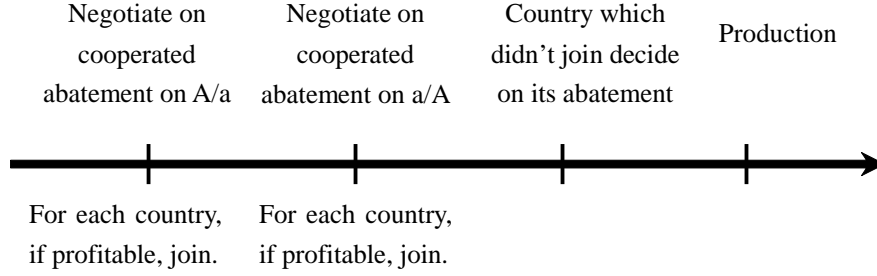


Figure 1: timing of the game

2.2.2 3rd stage of the game

Note that if in both stage 1 and 2, countries succeed in reaching an agreement, there would be no outcome from stage 3. Only when in any of the previous two stages the negotiation fails, the countries decide the abatement level of that pollutant in the 3rd stage. The equilibrium of the stage 3 is only contingent on the negotiation outcome of the previous two stages, but not on the negotiation sequence. Hence, it is solved backwards, the stage 3 is independent of the negotiation agenda, and the solution can be one of the following situations.

- Countries have formed an agreement on the local pollutant (\hat{a}_1, \hat{a}_2) , but not on the global one. Hence, at stage 3, each country makes a decision on the abatement level of global pollutant A_i that maximizes its own welfare, given the cooperative local pollutant abatement.

$$Max_{A_i} W_i(A_i, \hat{a}_i, \hat{a}_j) = \lambda_i(A_i + A_j) + \epsilon_i(\hat{a}_i + \gamma\hat{a}_j) - A_i^2 - \eta\hat{a}_1^2 - \sigma A_i\hat{a}_i \quad i, j = 1, 2, i \neq j$$

The first order condition and the equilibrium level of global pollutant abatement is:

$$-2A_i - \sigma\hat{a}_i + \lambda_i = 0 \quad i = 1, 2$$

$$A_i(\hat{a}_i, \hat{a}_j) = \frac{\lambda_i - \sigma \hat{a}_i}{2} \quad i, j = 1, 2, i \neq j \quad (2.1)$$

Note that in equilibrium, the global pollutant would be a function of the agreement on local pollutant (\hat{a}_i, \hat{a}_j) in general. In this simple model, the choice of abatement level is independent of the choice of the other country, but their national welfare does depend on the other country's move.

The equilibrium level of global pollutant abatement is decreasing in the agreement abatement level of local pollutant \hat{a}_i if pollutants are substitutes ($\sigma > 0$), and increasing otherwise ($\sigma < 0$). The result is so, as expected, because emission reduction is costly, and even more costly when one abates more. Hence, when pollutants are substitutes, choosing to control more one pollutant decreases the capability to control the other. On the contrary, when pollutants are complements, the process which abates one pollutant reduces the other at the same time, which encourages a country to control both environmental problems.

- The countries have formed an agreement on the global pollutant (\hat{A}_i, \hat{A}_j) , but not on the local one. Similarly, each country maximizes its welfare with respect to its own abatement level of the local pollutant, given the agreed level of global pollutant negotiated in the previous stage. The resulting equilibrium of local pollutant abatement is as follows. It is a decreasing function of the abatement level on the other pollutant when $\sigma > 0$, otherwise it is increasing if $\sigma < 0$, which again shows how the correlation effect plays a crucial role in the equilibrium of environmental regulations:

$$\begin{aligned} -2\eta a_i - \sigma \hat{A}_i + \epsilon_i &= 0 & i = 1, 2 \\ a_i(\hat{A}_i, \hat{A}_j) &= \frac{\epsilon_i - \sigma \hat{A}_i}{2\eta} & i, j = 1, 2, i \neq j \end{aligned} \quad (2.2)$$

- After the previous two stages' negotiations, no coalition is agreed upon. In this case, both countries choose their own national policies, i.e., the abatement level

of both pollutants, in a non-cooperative way. This yields the Nash equilibrium outcome.

$$A_i = \frac{2\eta\lambda_i - \sigma\epsilon_i}{4\eta - \sigma^2} \quad a_i = \frac{2\epsilon_i - \sigma\lambda_i}{4\eta - \sigma^2} \quad i = 1, 2$$

One would expect that the abatement level of an agreement is higher than the non-cooperative abatement level. Given this, I estimate the comparison of these three cases:

1) For the first and third cases on abatement level of the global pollutant, if I consider that pollutants are substitutes $\sigma > 0$, the level of abatement of the global pollutant A_i when no agreement is reached (third case) is higher than when countries have agreed on the local pollutant $A_i(\hat{a}_i, \hat{a}_j)$ in the first case, and the opposite if pollutants are complements $\sigma < 0$. That is, if $\hat{a}_i > a_i$, then $A_i > A_i(\hat{a}_i, \hat{a}_j)$ when $\sigma > 0$, or $A_i(\hat{a}_i, \hat{a}_j) > A_i$ when $\sigma < 0$.

2) With respect to the second and third cases on the abatement level of local pollutant, similar results yield. When $\sigma > 0$, the local pollutant of country i, a_i is higher when no agreement is reached (third case) than when an agreement is reached over the global pollutant (second case), $a_i(\hat{A}_i, \hat{A}_j)$. On the other hand, if pollutants are complements with $\sigma < 0$, each country imposes a stricter regulation on the local pollutant. i.e. if $\hat{A}_i > A_i$, then $a_i > a_i(\hat{A}_i, \hat{A}_j)$ when $\sigma > 0$, or $a_i(\hat{A}_i, \hat{A}_j) > a_i$ when $\sigma < 0$.

Comparing the abatement levels between the situation in which there is only one agreement and non-cooperative outcome, the relationship is summarized in the following table.

abatement level on	$\sigma > 0$		$\sigma < 0$	
	One agreement	Nash	One agreement	Nash
agreed pollutant	>		>	
the other pollutant	<		>	

The table reads as, when pollutants are substitutes ($\sigma > 0$), the abatement level on the pollutant is always higher than the Nash outcome, independently of which pollutant

the countries have reached an agreement on. However, the abatement level on the other pollutant which is not included in the treaty is lower than the non-cooperative situation. When pollutants are complements, the comparison result is different. Under the situation in which there is only one agreement, the abatement levels of both the agreed pollutant and the other pollutant are higher than the outcome under no agreement.

In general, when pollutants are substitutes, countries abate more on the pollutant which is in the agreement, but abate less of the other pollutant, comparing with the absolute non-cooperative case. It makes the environmental regulation strict in one dimension, but lax in the other. In contrast, when the pollutants are complements, comparing with the Nash equilibrium, the countries impose a stricter regulation towards both pollutants, making the non-cooperative strategy the least desirable one from the environmental perspective.

Solving the game further backwards from third stage on, the outcome is different with respect to the sequence of negotiations. I discuss in detail both sequences in two sections below.

2.3 Sequence aA

This section considers the case where the countries negotiate on local pollutant a at stage 1 and then at stage 2 on global pollutant A . By backward induction, I calculate the equilibrium outcome of the abatement level over A and then the one over the local pollutant a .

2.3.1 Stage 2

Depending on whether the countries have formed an agreement or not on the local pollutant in the first stage, the equilibrium outcome is different. I then introduce the two cases, and discuss them one by one.

1. Countries have formed an agreement on local pollutant a in the first stage (\hat{a}_1 ,

\hat{a}_2), and this agreement is binding. To see whether in the second stage countries are willing to sign the treaty or not, I compare the abatement level and the national welfare under two alternatives: without agreement and with agreement. A cooperation can be formed only if both countries are better off with the efficient abatement level in the treaty. From here on, whenever comparing the welfare difference, I first discuss the welfare and equilibrium for the non-cooperative case, and then discuss the case in which countries sign an agreement.

If countries do not cooperate, they decide their abatement of global pollutant strategically in stage 3, as shown in (2.1). I use the superscript N to denote the non-cooperative equilibrium, and C for the cooperation outcome.

$$A_i^N(\hat{a}_i, \hat{a}_j) = \frac{\lambda_i - \sigma \hat{a}_i}{2} \quad i, j = 1, 2, i \neq j \quad (2.3)$$

If both countries sign the treaty, they choose the abatement level of global pollutant for each country to maximize the joint welfare as follows:

$$\text{Max}_{A_i, A_j} \sum_{i=1}^2 W_i(\hat{a}_i, \hat{a}_j, A_i, A_j) = \sum_{i=1}^2 [\lambda_i(A_i + A_j) + \epsilon_i(\hat{a}_i + \gamma \hat{a}_j) - A_i^2 - \eta \hat{a}_i^2 - \sigma A_i \hat{a}_i] \quad (2.4)$$

The cooperative equilibrium of global pollutant for country i is:

$$A_i^C(\hat{a}_i, \hat{a}_j) = \frac{\lambda_i + \lambda_j - \sigma \hat{a}_i}{2} \quad i, j = 1, 2, i \neq j \quad (2.5)$$

Given the abatement level in the first stage, the welfare difference measured as the welfare under an agreement minus the non-cooperative welfare for each country can be obtained, as in the following:

$$\Delta W_i = \frac{2\lambda_i^2 - \lambda_j^2}{4} \quad i, j = 1, 2, i \neq j \quad (2.6)$$

It is straightforward that the previously agreed abatement level does not have an effect on the welfare difference of the second stage, or say, the agreement decision. The welfare difference is affected only by the environmental concerns or the marginal benefit

of the global pollutant λ . Hence, for the countries to be willing to join the agreement, it must be that $\Delta W_i > 0$ for both countries. This is true under the following condition:

$$\frac{\lambda_i^2}{\lambda_j^2} \in \left(\frac{1}{2}, 2\right) \quad i, j = 1, 2, i \neq j \quad (2.7)$$

More specifically, the requirement for the agreement to hold is that both countries have a similar concern over the global environment. I denote the situation where countries do not cooperate as "no(2.7)", which is, $\frac{\lambda_i^2}{\lambda_j^2} \notin \left(\frac{1}{2}, 2\right)$. As for the abatement level of global pollutant, it is described in the following lemma. As expected, the abatement level under an agreement is higher than that in a non-cooperative way. The above analysis implies the following lemma.

Lemma 2.1 *When countries have formed an agreement on the local pollutant a in the first stage, the abatement level of global pollutant A_i in the second stage would be: 1) $\frac{\lambda_i - \sigma \hat{a}_i}{2}$ if $\frac{\lambda_i^2}{\lambda_j^2} \notin \left(\frac{1}{2}, 2\right)$, $i, j = 1, 2$ $i \neq j$, in this case no cooperation is formed; 2) $\frac{\lambda_i + \lambda_j - \sigma \hat{a}_i}{2}$ if $\frac{\lambda_i^2}{\lambda_j^2} \in \left(\frac{1}{2}, 2\right)$, $i, j = 1, 2$, $i \neq j$ where countries sign an agreement on the global pollutant.*

2. Countries did not form an agreement on local pollutant a in the first stage. Since in the first stage no agreement is signed and no abatement level on local pollutant is decided, they choose it in a non-cooperative way at the third stage, given by the reaction function (2.2). Substituting (2.2) in the welfare function for each country, its decision on the abatement of global pollutant in the second stage is based on the following welfare function:

$$W_i(a_i, a_j, A_i, A_j) = \left(\frac{\sigma^2}{4\eta} - 1\right) (A_i^2 + \lambda_i A_i + A_j) + \epsilon_i \left(\frac{\epsilon_i - \sigma A_i}{2\eta} + \gamma \frac{\epsilon_j - \sigma A_j}{2\eta}\right) \quad (2.8)$$

If, in the second stage countries do not form any agreement, each country maximizes their own welfare function corresponding to the status quo and gets the equilibrium of global pollutant's reduction as:

$$A_i^N = \frac{2\eta\lambda_i - \sigma\epsilon_i}{4\eta - \sigma^2} \quad i = 1, 2 \quad (2.9)$$

If countries form an agreement on the global pollutant, they maximize their joint welfare, and the cooperative abatement level is:

$$A_i^C = \frac{2\eta\lambda_i - \sigma\epsilon_i + 2\eta\lambda_j - \gamma\sigma\epsilon_j}{4\eta - \sigma^2} \quad i, j = 1, 2, i \neq j \quad (2.10)$$

Correspondingly, the local pollutant abatement level in the third stage is:

$$a_i(A_i^C, A_j^C) = \frac{\epsilon_i - \sigma A_i^C}{2\eta} = \frac{2\epsilon_i - \sigma\lambda_i + \frac{\sigma^2\gamma}{2\eta}\epsilon_j - \sigma\lambda_j}{4\eta - \sigma^2} \quad i, j = 1, 2, i \neq j \quad (2.11)$$

Substituting the abatement levels of global pollutant (2.9) and (2.10) into (2.8), respectively, the welfare difference between the cooperation and non-cooperation case is:

$$\Delta W_i = \frac{1}{4\eta(4\eta - \sigma^2)} [2(2\eta\lambda_i - \gamma\sigma\epsilon_i)^2 - (2\eta\lambda_j - \gamma\sigma\epsilon_j)^2] \quad i, j = 1, 2, i \neq j \quad (2.12)$$

Hence, for an agreement to form in this situation rather than a negotiation failure, the following condition (2.13) needs to hold for both countries.

$$\frac{\left(\lambda_i - \frac{\gamma\sigma\epsilon_i}{2\eta}\right)^2}{\left(\lambda_j - \frac{\gamma\sigma\epsilon_j}{2\eta}\right)^2} \in \left(\frac{1}{2}, 2\right) \quad i, j = 1, 2, i \neq j \quad (2.13)$$

Note that this form is very similar to the agreement condition in the previous case in (2.7), but it depends on correlation coefficient, spillover effect and cost parameter as well. Since this condition depends on more parameters, one may conclude that when countries have not reached an agreement in the first stage they take into account more factors in the negotiation of the second stage than if they successfully reached an agreement in the first period. Consequently, it makes the second stage negotiation more complex. In other words, when countries sign an environmental treaty in the first stage, it facilitates their next period's negotiation.

Corollary 2.2 *If countries have not formed an agreement in the first stage, the negotiation in the following period is more complex than when countries have cooperated previously, in the sense that more parameters need to be considered.*

Besides, I denote the situation where countries do not cooperate as no(2.13), which is $\frac{(\lambda_i - \frac{\gamma\sigma\epsilon_i}{2\eta})^2}{(\lambda_j - \frac{\gamma\sigma\epsilon_j}{2\eta})^2} \notin (\frac{1}{2}, 2)$. The corresponding abatement level of global pollutant I solved above concludes to the next Lemma.

Lemma 2.3 *When countries have not formed any agreement on local pollutant in the first stage, the equilibrium abatement level of global pollutant A_i in the second stage would be equal to:*

- 1) $\frac{2\eta\lambda_i - \sigma\epsilon_i}{4\eta - \sigma^2}$ if $\frac{(\lambda_i - \frac{\gamma\sigma\epsilon_i}{2\eta})^2}{(\lambda_j - \frac{\gamma\sigma\epsilon_j}{2\eta})^2} \notin (\frac{1}{2}, 2)$, $i, j = 1, 2$ $i \neq j$, in this case no cooperation is formed;
- 2) $\frac{2\eta\lambda_i - \sigma\epsilon_i + 2\eta\lambda_j - \gamma\sigma\epsilon_j}{4\eta - \sigma^2}$ if $\frac{(\lambda_i - \frac{\gamma\sigma\epsilon_i}{2\eta})^2}{(\lambda_j - \frac{\gamma\sigma\epsilon_j}{2\eta})^2} \in (\frac{1}{2}, 2)$ for $i, j = 1, 2$ $i \neq j$, where countries sign an agreement on global pollutant.

2.3.2 Stage 1

Countries are forward-looking agents. By subgame perfect equilibrium, when the countries negotiate on the local pollutant abatement level in the first stage, they take into account what will happen in the next stage. Four possible cases arise.

1. Parameters fall into conditions no(2.7) and no(2.13), which are $\frac{\lambda_i^2}{\lambda_j^2} \notin (\frac{1}{2}, 2)$ and $\frac{(\lambda_i - \frac{\gamma\sigma\epsilon_i}{2\eta})^2}{(\lambda_j - \frac{\gamma\sigma\epsilon_j}{2\eta})^2} \notin (\frac{1}{2}, 2)$, for $i, j = 1, 2$ $i \neq j$. This corresponds to a situation in which both countries expect that they will cooperate in the next stage no matter what happens in the current period.

In the subgame where countries do not form any agreement in the first stage, countries decide on their abatement level of local pollutant at the last stage which is solved at (2.11), that is,

$$a_i^N = \frac{2\epsilon_i - \sigma\lambda_i + \frac{\sigma^2\gamma}{2\eta}\epsilon_j - \sigma\lambda_j}{4\eta - \sigma^2} \quad i, j = 1, 2, \quad i \neq j$$

In the subgame in which countries form an agreement in the first stage, substituting the response function (2.5) into each country's welfare objective yields:

$$W_i(a_i^C, a_j^C, A_i^C, A_j^C) = \left(\frac{\sigma^2}{4} - \eta\right) a_i^2 - \frac{(\lambda_i + \lambda_j)^2}{4} + \lambda_i \left(\lambda_i + \lambda_j - \frac{a_i + a_j}{2} \sigma\right) + \epsilon_i(a_i + \gamma a_j) \quad (2.14)$$

Maximizing the joint welfare, the cooperating equilibrium level of local pollutant can be obtained as:

$$a_i^C = \frac{2\epsilon_i - \sigma\lambda_i + 2\gamma\epsilon_j - \sigma\lambda_j}{4\eta - \sigma^2} \quad i, j = 1, 2, \quad i \neq j \quad (2.15)$$

The corresponding abatement level of global pollutant can be recovered by (5). Subsequently, the welfare difference is calculated as:

$$\Delta W_i = \frac{\gamma^2}{4\eta} (2\epsilon_i^2 - \epsilon_j^2) \quad i, j = 1, 2, \quad i \neq j \quad (2.16)$$

Hence, countries i and j are willing to sign an agreement only if $\frac{\epsilon_i^2}{\epsilon_j^2} \in (\frac{1}{2}, 2)$. This condition is similar with condition (2.7) in 3.1.1. The only difference is that in stage 2, when the theme of negotiation is the global pollutant, the key element is the concern about the global pollutant; while in the stage 1, when countries are gathering together to negotiate on local pollutant, the importance lies on the concern on local pollutant. To be more clear, since condition no(2.7) and no(2.13) implicate that no matter what happened in the first period, countries cooperate in the later stage, this together with the condition obtained as $\frac{\epsilon_i^2}{\epsilon_j^2} \in (\frac{1}{2}, 2)$, characterize a situation that in both stages an agreement is formed. Otherwise, if $\frac{\epsilon_i^2}{\epsilon_j^2} \notin (\frac{1}{2}, 2)$, together with no(2.7) and no(2.13), it leads to the situation that in the first stage countries fail to cooperate but in the second stage they sign the treaty. If using C and N to denote cooperation and non-cooperation respectively, and the sequence of letters to represent the outcome of each stage, then the cooperation result can be written as in the following proposition.

Proposition 2.4 *i) NC: Countries fail to cooperate on local pollutant in the first stage but manage to reach an agreement on the global one in the second period, if $\frac{\lambda_i^2}{\lambda_j^2} \in (\frac{1}{2}, 2)$, $\frac{(\lambda_i - \frac{\gamma\sigma\epsilon_i}{2\eta})^2}{(\lambda_j - \frac{\gamma\sigma\epsilon_j}{2\eta})^2} \in (\frac{1}{2}, 2)$ and $\frac{\epsilon_i^2}{\epsilon_j^2} \notin (\frac{1}{2}, 2)$, for $i, j = 1, 2 \quad i \neq j$.*

ii) *CC*: Countries cooperate on both pollutants at both stages, if $\frac{\lambda_i^2}{\lambda_j^2} \in (\frac{1}{2}, 2)$, $\frac{(\lambda_i - \frac{\gamma\sigma\epsilon_i}{2\eta})^2}{(\lambda_j - \frac{\gamma\sigma\epsilon_j}{2\eta})^2} \in (\frac{1}{2}, 2)$ and $\frac{\epsilon_i^2}{\epsilon_j^2} \in (\frac{1}{2}, 2)$, for $i, j = 1, 2$ $i \neq j$.

In these two cases, the equilibrium abatement levels of local pollutant are the following. Note that because $2\gamma\epsilon_j > \frac{\sigma^2\gamma}{2\eta}\epsilon_j$, the abatement level under an agreement is always higher.

$$a_i = \begin{cases} \frac{2\epsilon_i - \sigma\lambda_i + \frac{\sigma^2\gamma}{2\eta}\epsilon_j - \sigma\lambda_j}{4\eta - \sigma^2} & \text{if NC} \\ \frac{2\epsilon_i - \sigma\lambda_i + 2\gamma\epsilon_j - \sigma\lambda_j}{4\eta - \sigma^2} & \text{if CC} \end{cases} \quad i, j = 1, 2, i \neq j \quad (2.17)$$

2. Parameters fall into conditions (2.7) and (2.13), indicating that countries have the expectation that there will be no agreement in the second stage, independently of what happens in the first period.

If no agreement is reached at this stage, which means no agreement exists in any of the two stages. Countries decide their equilibrium abatement levels according to the Nash equilibrium, solved previously:

$$A_i^N = \frac{2\eta\lambda_i - \sigma\epsilon_i}{4\eta - \sigma^2}, \quad a_i^N = \frac{2\epsilon_i - \sigma\lambda_i}{4\eta - \sigma^2} \quad i = 1, 2 \quad (2.18)$$

Taking into consideration the reaction function (2.1) in the total welfare, I get the equilibrium abatement for the local pollutant and also the corresponding abatement level of global pollutant as below:

$$a_i^C = \frac{2\epsilon_i - \sigma\lambda_i + 2\gamma\epsilon_j - \sigma\lambda_j}{4\eta - \sigma^2} \quad i, j = 1, 2, i \neq j \quad (2.19)$$

$$A_i^C = \frac{\lambda_i - \sigma a_i^C}{2} = \frac{2\eta\lambda_i - \sigma\epsilon_i + \frac{\sigma^2}{2}\lambda_j - \gamma\sigma\epsilon_j}{4\eta - \sigma^2} \quad i, j = 1, 2, i \neq j \quad (2.20)$$

The welfare improvement of a cooperation comparing to the status quo is given as:

$$\Delta W_i = \frac{1}{4(4\eta - \sigma^2)} [2(2\gamma\epsilon_i - \sigma\lambda_i)^2 - (2\gamma\epsilon_j - \sigma\lambda_j)^2] \quad i = 1, 2 \quad (2.21)$$

Hence, if $2(2\gamma\epsilon_i - \sigma\lambda_i)^2 - (2\gamma\epsilon_j - \sigma\lambda_j)^2 > 0$ which is equivalent to the condition $\frac{(\epsilon_i - \frac{\sigma\lambda_i}{2\gamma})^2}{(\epsilon_j - \frac{\sigma\lambda_j}{2\gamma})^2} \in (\frac{1}{2}, 2)$, reaching an agreement is more favorable. Together with conditions (2.7) and (2.13) which imply that countries refuse to cooperate in the second stage no matter what happened before, it results in the situation where in the first stage an agreement is formed on the local pollutant, but no cooperation later. On the contrary, if $\frac{(\epsilon_i - \frac{\sigma\lambda_i}{2\gamma})^2}{(\epsilon_j - \frac{\sigma\lambda_j}{2\gamma})^2} \notin (\frac{1}{2}, 2)$, together with (2.7) and (2.13), it leads to the situation that the negotiation failed in both stages. This corresponds to the following proposition.

Proposition 2.5 *i) NN: Countries fail in the negotiation during both stages, if $\frac{\lambda_i^2}{\lambda_j^2} \notin (\frac{1}{2}, 2)$, $\frac{(\lambda_i - \frac{\gamma\sigma\epsilon_i}{2\eta})^2}{(\lambda_j - \frac{\gamma\sigma\epsilon_j}{2\eta})^2} \notin (\frac{1}{2}, 2)$ and $\frac{(\epsilon_i - \frac{\sigma\lambda_i}{2\gamma})^2}{(\epsilon_j - \frac{\sigma\lambda_j}{2\gamma})^2} \notin (\frac{1}{2}, 2)$, for $i, j = 1, 2$ $i \neq j$.*

ii) CN: Countries sign an agreement on the local pollutant in the first stage but not on the other pollutant later, if $\frac{\lambda_i^2}{\lambda_j^2} \notin (\frac{1}{2}, 2)$, $\frac{(\lambda_i - \frac{\gamma\sigma\epsilon_i}{2\eta})^2}{(\lambda_j - \frac{\gamma\sigma\epsilon_j}{2\eta})^2} \notin (\frac{1}{2}, 2)$ and $\frac{(\epsilon_i - \frac{\sigma\lambda_i}{2\gamma})^2}{(\epsilon_j - \frac{\sigma\lambda_j}{2\gamma})^2} \in (\frac{1}{2}, 2)$, for $i, j = 1, 2$ $i \neq j$.

In these two situations, the equilibrium abatement levels of local pollutant are presented below.

$$a_i = \begin{cases} \frac{2\epsilon_i - \sigma\lambda_i}{4\eta - \sigma^2} & \text{if NN} \\ \frac{2\epsilon_i - \sigma\lambda_i + 2\gamma\epsilon_j - \sigma\lambda_j}{4\eta - \sigma^2} & \text{if CN} \end{cases} \quad i, j = 1, 2, \quad i \neq j \quad (2.22)$$

3. Parameters fall into conditions no(2.7) and (2.13), suggesting that countries expect to have cooperation in the following stage after a successful agreement, and no agreement after a cooperation failure.

Having known the abatement level in each case, substitute them back into the welfare function for each country:

$$\begin{aligned} \Delta W_i &= -(2\eta\lambda_j - \gamma\sigma\epsilon_j)^2 - \eta(2\gamma\epsilon_j - \sigma\lambda_j)^2 - \sigma(2\eta\lambda_j - \gamma\sigma\epsilon_j)(2\gamma\epsilon_j - \sigma\lambda_j) \\ &\quad + (4\eta - \sigma^2)[\lambda_i(2\eta\lambda_j - \gamma\sigma\epsilon_j) + \epsilon_i(2\gamma\epsilon_j - \sigma\lambda_j)] \end{aligned} \quad (2.23)$$

I denote the equation (2.23) as Ω , where $\Omega > 0$ represents that cooperation occurs. This condition is not similar to the previous agreement conditions, because depending

on what has been achieved in the first period, the cooperation outcome in the second stage is distinctive. Hence, if $\Omega > 0$, and combining with conditions no(2.7) and (2.13), one can predict that there are cooperations in both stages. On the contrary, if $\Omega < 0$, together with no(2.7) and (2.13), it corresponds to the situation that negotiation fails in both periods.

Proposition 2.6 *i) NN: Countries do not cooperate for both pollutants in any stage if $\frac{\lambda_i^2}{\lambda_j^2} \in (\frac{1}{2}, 2)$, $\frac{(\lambda_i - \frac{\gamma\sigma\epsilon_i}{2\eta})^2}{(\lambda_j - \frac{\gamma\sigma\epsilon_j}{2\eta})^2} \notin (\frac{1}{2}, 2)$ and $\Omega < 0$ for $i, j = 1, 2$ $i \neq j$;*

ii) CC: Countries succeed in the cooperation of both stages if $\frac{\lambda_i^2}{\lambda_j^2} \in (\frac{1}{2}, 2)$, $\frac{(\lambda_i - \frac{\gamma\sigma\epsilon_i}{2\eta})^2}{(\lambda_j - \frac{\gamma\sigma\epsilon_j}{2\eta})^2} \notin (\frac{1}{2}, 2)$ and $\Omega > 0$, $i, j = 1, 2$ $i \neq j$.

The equilibrium abatement levels of local pollutant are:

$$a_i = \begin{cases} \frac{2\epsilon_i - \sigma\lambda_i + \frac{\sigma^2\gamma}{2\eta}\epsilon_j - \sigma\lambda_j}{4\eta - \sigma^2} & \text{if NN} \\ \frac{2\epsilon_i - \sigma\lambda_i + 2\gamma\epsilon_j - \sigma\lambda_j}{4\eta - \sigma^2} & \text{if CC} \end{cases} \quad i, j = 1, 2, \quad i \neq j \quad (2.24)$$

4. Parameters fall into conditions (2.7) and no(2.13), corresponding to a situation in which countries expect to have a cooperation if they fail to do it previously, and they expect not to have a treaty signed in the following period if they have already cooperated before.

The welfare difference between cooperation and non-cooperation is computed as:

$$\Delta W_i = (\eta - \frac{\sigma^2}{4})\lambda_j^2 - \gamma^2(\frac{\sigma^2}{2\eta} - \frac{\sigma^2}{4} - \eta) + (4\eta - \sigma^2)(\frac{\gamma^2\epsilon_i^2}{2\eta} - \frac{1}{2}\lambda_i^2) \quad i, j = 1, 2, \quad i \neq j \quad (2.25)$$

The condition (2.25) is denoted as Φ , where $\Phi > 0$ indicates that countries prefer an agreement than nothing. Hence, if $\Phi > 0$, and combining with conditions (2.7) and no(2.13), these three inequalities result in the situation that only in the first stage a coalition is formed, while if otherwise, $\Phi < 0$, together with (2.7) and no(2.13), one can predict that only in the second stage a coalition occurs.

Proposition 2.7 *i) NC: Countries only form cooperation for the global pollutant in the second stage if $\frac{\lambda_i^2}{\lambda_j^2} \notin (\frac{1}{2}, 2)$, $\frac{(\lambda_i - \frac{\gamma\sigma\epsilon_i}{2\eta})^2}{(\lambda_j - \frac{\gamma\sigma\epsilon_j}{2\eta})^2} \in (\frac{1}{2}, 2)$ and $\Phi < 0$ for $i, j = 1, 2$ $i \neq j$;*

ii) CN: Countries only form agreement for the local pollutant in the first stage if $\frac{\lambda_i^2}{\lambda_j^2} \notin (\frac{1}{2}, 2)$, $\frac{(\lambda_i - \frac{\gamma\sigma\epsilon_i}{2\eta})^2}{(\lambda_j - \frac{\gamma\sigma\epsilon_j}{2\eta})^2} \in (\frac{1}{2}, 2)$ and $\Phi > 0$, $i, j = 1, 2$ $i \neq j$.

Accordingly, the equilibrium abatement levels of the local pollutant are:

$$a_i = \begin{cases} \frac{2\epsilon_i - \sigma\lambda_i}{4\eta - \sigma^2} & \text{if NC} \\ \frac{2\epsilon_i - \sigma\lambda_i + 2\gamma\epsilon_j - \sigma\lambda_j}{4\eta - \sigma^2} & \text{if CN} \end{cases} \quad i, j = 1, 2, \quad i \neq j \quad (2.26)$$

It can be observed that in all four cases the abatement level under cooperation is always higher than that under non-cooperation: $a_i^C > a_i^N$, $i = 1, 2$. It simply suggests that when under an agreement, each country bears more responsibility and imposes a stricter regulation on that pollutant. Given that it is welfare improving when both countries decide to sign the agreement, it is also environmentally beneficial for both at the same time, which is why countries cooperate to solve the externality problem and create a win-win solution.

All the possible equilibrium outcomes in all parameter regions are known. As long as one knows the value of parameters, country's environmental concern (or marginal benefit for pollution abatement), correlation effect characterized by certain technology, cost coefficient and the spillover effect, whether a negotiation is a success or failure and the according abatement details for each country are predictable. Hence, it could explain the membership behavior of each country in each agreement negotiation. I discuss a few specific examples below.

First, in symmetric case $\epsilon_i = \epsilon_j$, $\lambda_i = \lambda_j$, countries's concern on each pollutant is the same. Irrespective of other parameters, this leads to a happy ending in which a cooperation can be obtained in each stage, countries deal together with the negative externalities.

Second, if $\epsilon_i = \lambda_i \neq \epsilon_j = \lambda_j$, countries do not distinguish global pollutant from the local one, but regard the whole environment in the same way, as implied in most of the

paper of one pollutant and one concern on the environment. In this case, an agreement is achieved in both stages if $\frac{\epsilon_i^2}{\epsilon_j^2} \in (\frac{1}{2}, 2)$; otherwise non-cooperation in both stages. It suggests that when countries consider the environment in a general sense, then they are always willing to sign the treaty when both countries have similar concerns. On the contrary, if their opinion on the environment is too divergent, there can never be any cooperation. In this case, either cooperation is always achieved, or no cooperation ever.

Third, I consider the case in which two countries are asymmetric as $\epsilon_i \neq \epsilon_j, \lambda_i = \lambda_j$, representing that they have the same opinion on the global environment, but one country may care more about the local pollutant than the other. For simplicity, I assume here that $\lambda_1 = \lambda_2 = \epsilon_1 < \epsilon_2$, signifying with other concerns of the two countries equal, country 2 is more environmentally concerned especially on the local pollutant.

At the first point, I consider the effects of countries' relative concerns and the correlation coefficient, leaving other parameters constant. Later the effects of other parameters on the negotiation outcome are also discussed. Let $\frac{\epsilon_2}{\epsilon_1} = x$, the spillover coefficient $\gamma = \frac{1}{2}$ and the relative abatement unit cost for local pollutant $\eta = \frac{1}{2}$, where the abatement for global pollutant is twice more costly than reducing the local one. After simplifying the conditions for an agreement to hold in all the regions for this negotiation sequence aA, I list all possible cooperations. For those not listed, it falls to the situation in which no agreement is signed in any period.

Region 1 (2.3.2.1):

$$CC \Leftrightarrow \begin{cases} x < \min \left\{ \sqrt{2}, \frac{2+2\sqrt{2}}{\sigma} - \sqrt{2} \right\} & \text{if } \sigma > 0 \\ x < \min \left\{ \sqrt{2}, \frac{2-2\sqrt{2}}{\sigma} + \sqrt{2} \right\} & \text{if } \sigma < 0 \end{cases}$$

$$NC \Leftrightarrow \begin{cases} \sqrt{2} < x < \frac{2+2\sqrt{2}}{\sigma} - \sqrt{2} & \text{if } \sigma > 0 \\ \sqrt{2} < x < \frac{2-2\sqrt{2}}{\sigma} + \sqrt{2} & \text{if } \sigma < 0 \end{cases}$$

Region 2 (2.3.2.2): does not exist because $\lambda_1 = \lambda_2$.

Region 3 (2.3.2.3):

$$CC \Leftrightarrow \begin{cases} \frac{2+2\sqrt{2}}{\sigma} - \sqrt{2} < x < 2 + 2\sqrt{1.5 - \sigma} & \text{if } \sigma > 0 \\ \frac{2-2\sqrt{2}}{\sigma} + \sqrt{2} < x < 2 + 2\sqrt{1.5 - \sigma} & \text{if } \sigma < 0 \end{cases}$$

Region 4 (2.3.2.4): does not exist because of $\lambda_1 = \lambda_2$.

To make the result more straightforward, a figure is drawn in the following. In the plot, x-axis is σ which ranges between -2 and 2; the y-axis is the concern ratio of two countries $\frac{e_2}{e_1}$. The negotiation outcome NC, which signifies non-cooperation in local pollutant but an agreement on global pollutant, corresponds to the area between the solid curve and the straight line $\sqrt{2}$. For the negotiation outcome CC, there are two areas of successful cooperation for both issues. One lies below the straight line, the other lies between the red solid and the green dash line on the left part. All other areas represent that no treaties signed in any stage.

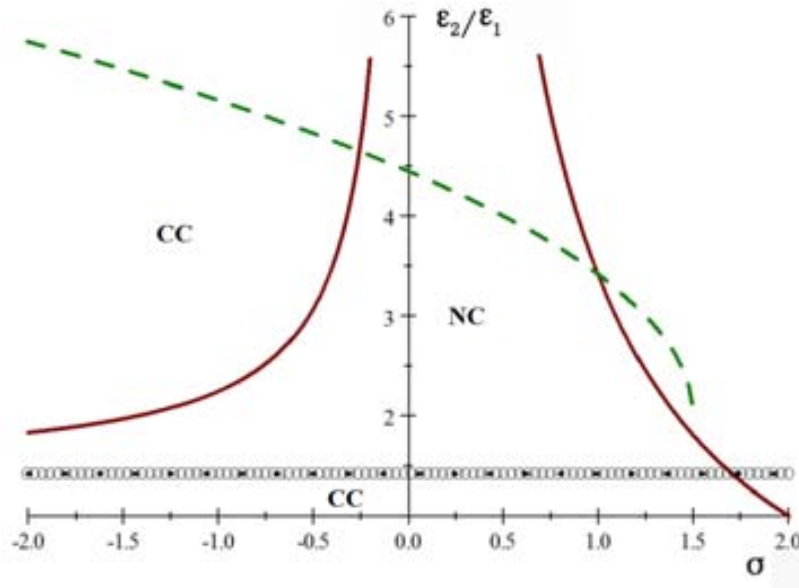


Figure 2: negotiation outcome for sequence aA

The first discover is that the correlation coefficient σ plays a role in international agreement negotiations, where obviously when σ gets smaller and smaller, the area for a cooperation (both the outcome of one treaty and two successful treaties) becomes bigger and bigger. Put it differently, as σ decreases, it yields cooperation for a wider range of parameter values, thereby the possibility that cooperation can be achieved is getting higher. This is intuitive, because when $\sigma < 0$, which makes the pollutants complementary, abating one pollutant is beneficial for the reduction of the other pollutant, the save

on the abatement cost thereby makes the negotiation of solving the externalities much easier. Secondly, for the area where $\frac{\epsilon_2}{\epsilon_1} < \sqrt{2}$, where countries may not have exactly the same concern on the local pollutant, but similar. It shows that as long as the countries hold a similar opinion over the environmental theme, they can successfully cooperate on both pollutants' issues, irrespective of the characteristics of abatement technologies σ . Third, in the situation where countries have the same concern on the global pollutant but different opinion on the local one, if countries can only be successful in signing one agreement, it would be cooperation on the global pollutant. This conclusion is expected, that the countries tend to more easily reach a mutual consensus on one issue in which they both have a common interest.

Moreover, the same can be done to evaluate the effect of other parameters, the spillover effect γ and the cost coefficient η . For the effect of γ , I fix $\eta = \frac{1}{2}$, vary σ as either $\sigma = \frac{1}{2}$ or $\sigma = -\frac{1}{2}$ to represent both substitutive and complementary situations of pollutants. When pollutants are substitutes, the countries sign the treaties in both periods for both pollutants if $\frac{\epsilon_2}{\epsilon_1} < \sqrt{2}$ and they cooperate only on global pollutant if $\sqrt{2} < \frac{\epsilon_2}{\epsilon_1} < \frac{2\sqrt{2}+2}{\gamma} - \sqrt{2}$. When pollutants are complementary with $\sigma = -\frac{1}{2}$, countries form a coalition in both stages if $\frac{\epsilon_2}{\epsilon_1} < \sqrt{2}$ or $\frac{2\sqrt{2}-2}{\gamma} + \sqrt{2} < \frac{\epsilon_2}{\epsilon_1} < \frac{1+\sqrt{2}}{\gamma}$, and in between these two areas $\sqrt{2} < \frac{\epsilon_2}{\epsilon_1} < \frac{2\sqrt{2}-2}{\gamma} + \sqrt{2}$ is the outcome that countries only form one agreement in the second stage for the global pollutant. If considering both one agreement and two agreements as cooperation, the area which makes countries willing to cooperate gets bigger when γ gets smaller, no matter pollutants are substitutes or complements. Thus, it makes sense that the smaller the spillover effect of local pollutant is, or in other word, the smaller the externality is, more countries would be attracted to the environmental treaty.

In order to capture the effect of the relative abatement cost parameter η , I fix $\gamma = \frac{1}{2}$, vary σ as either $\sigma = \frac{1}{2}$ or $\sigma = -\frac{1}{2}$. Simplifying the equilibrium conditions, I obtain that when pollutants are substitutes, countries form a coalition in both stages if

$$\frac{\epsilon_2}{\epsilon_1} < \sqrt{2} \text{ or } 8 \left(1 + \sqrt{2} \right) \eta - \sqrt{2} < \frac{\epsilon_2}{\epsilon_1} < 2 \left(\sqrt{\eta + \frac{1}{2}} + 1 \right) \quad \eta \in (0, 1]$$

and countries only form one agreement in the second stage for the global pollutant if $\sqrt{2} < \frac{\varepsilon_2}{\varepsilon_1} < 8(1 + \sqrt{2})\eta - \sqrt{2}$. Similar results hold when pollutants are complements. For any kind of cooperation, as η gets bigger, the possibility that countries are willing to sign the treaty is higher. This conforms with intuition that as the relative abatement cost of local pollutant gets more and more close to that of the global pollutant, or the abatement cost of global pollutant becomes cheaper and cheaper, the negotiation becomes easier and easier. For two pollutants which abatement costs are very different, it only makes the negotiation worse, in both stages. Note that the result remains the same with respect to the other negotiation agenda, hence I present the proposition derived from the above analysis in the following.

Proposition 2.8 *When both countries have the same concern over the global pollutant and country 1 is more concerned on the local pollutant, under the negotiation agenda aA:*

i) The possibility that countries can successfully cooperate (either for one pollutant or for both) decreases with the correlation coefficient σ and the spillover effect γ , while increases with the relative cost parameter η .

ii) if countries can only be successful in reaching one agreement, it would be an cooperation on global pollutant where both countries have the same concern.

More details and intuitions are discussed in Section 2.5.

2.4 Sequence Aa

The sequence of agreement negotiation is exogenous, it can be the way of starting with the local pollutant as analyzed in the previous section, or it can be the other way around. In this section, I discuss the other sequence that countries first negotiate on the global pollutant on their political agenda, then on the local one. The calculation process is similar, but the result is not. Thus this section is concise in the calculation process and more attention is paid to the equilibrium outcomes.

2.4.1 Stage 2

1. If in the first stage countries form an agreement on global pollutant A .

When in the first stage countries have already formed an agreement, comparing the welfare between cooperation and non-cooperation cases, the solution of the welfare difference is the same with condition (2.16) in the Stage 1.1 (section 2.3.2.1) of sequence aA because NC in sequence aA is the same with CN in sequence Aa while solving, which is $\Delta W_i = \frac{\gamma^2}{4\eta}(2\epsilon_i^2 - \epsilon_j^2)$. The abatement level of local pollutant under both cooperation and non-cooperation case is $(\hat{A}_i, \hat{A}_j$ is given) the following.

Lemma 2.9 *When countries have formed an agreement on the global pollutant in the first stage, the abatement level of local pollutant in the second stage a_i would be: 1) $\frac{\epsilon_i - \sigma \hat{A}_i}{2\eta}$ if $\frac{\epsilon_i^2}{\epsilon_j^2} \notin (\frac{1}{2}, 2)$, $i, j = 1, 2$ $i \neq j$, in this case no cooperation is formed; 2) $\frac{\epsilon_i + \epsilon_j - \sigma \hat{A}_i}{2\eta}$ if $\frac{\epsilon_i^2}{\epsilon_j^2} \in (\frac{1}{2}, 2)$, where countries sign an agreement on the local pollutant.*

2. If in the first stage countries did not form an agreement on global pollutant A .

Again, when in the first stage a negotiation failed, the welfare difference between cooperation and non-cooperation is the same with Stage 1.2 (section 2.3.2.2) of sequence aA, because CN in sequence aA is the same with NC in sequence Aa. The equilibrium result is presented in the following lemma.

Lemma 2.10 *When countries did not form an agreement on global pollutant in the first stage, the abatement level of local pollutant in the second stage a_i would be: 1) $\frac{2\epsilon_i - \sigma \lambda_i}{4\eta - \sigma^2}$ if $\frac{(\lambda_i - \frac{\gamma\sigma\epsilon_i}{2\eta})^2}{(\lambda_j - \frac{\gamma\sigma\epsilon_j}{2\eta})^2} \notin (\frac{1}{2}, 2)$, $i, j = 1, 2$ $i \neq j$, in this case no cooperation is formed; 2) $\frac{2\epsilon_i - \sigma \lambda_i + 2\gamma\epsilon_j - \sigma \lambda_j}{4\eta - \sigma^2}$ if $\frac{(\lambda_i - \frac{\gamma\sigma\epsilon_i}{2\eta})^2}{(\lambda_j - \frac{\gamma\sigma\epsilon_j}{2\eta})^2} \in (\frac{1}{2}, 2)$, where countries sign an agreement on local pollutant.*

2.4.2 Stage 1

By backward induction, it comes to the first stage with forward-looking countries. The calculation method is similar, which is omitted here. In this section, the outcome is not

presented region by region, but in a combined way.

Proposition 2.11 *If countries negotiate according to the agenda that global pollutant is first negotiated and the local pollutant later, the equilibrium outcome would be:*

i) CC: Countries achieve full cooperation in both stages if

$$\begin{aligned} \text{either } \frac{\epsilon_i^2}{\epsilon_j^2} \in \left(\frac{1}{2}, 2\right), \frac{\left(\epsilon_i - \frac{\sigma\lambda_i}{2\gamma}\right)^2}{\left(\epsilon_j - \frac{\sigma\lambda_i}{2\gamma}\right)^2} \in \left(\frac{1}{2}, 2\right) \text{ and } \frac{\lambda_i^2}{\lambda_j^2} \in \left(\frac{1}{2}, 2\right) \\ \text{or } \frac{\epsilon_i^2}{\epsilon_j^2} \in \left(\frac{1}{2}, 2\right), \frac{\left(\epsilon_i - \frac{\sigma\lambda_i}{2\gamma}\right)^2}{\left(\epsilon_j - \frac{\sigma\lambda_i}{2\gamma}\right)^2} \notin \left(\frac{1}{2}, 2\right) \text{ and } \Omega > 0 \quad i, j = 1, 2, i \neq j \end{aligned}$$

ii) NC: Countries only form an agreement on local pollutant in the second stage if

$$\begin{aligned} \text{either } \frac{\epsilon_i^2}{\epsilon_j^2} \in \left(\frac{1}{2}, 2\right), \frac{\left(\epsilon_i - \frac{\sigma\lambda_i}{2\gamma}\right)^2}{\left(\epsilon_j - \frac{\sigma\lambda_i}{2\gamma}\right)^2} \in \left(\frac{1}{2}, 2\right) \text{ and } \frac{\lambda_i^2}{\lambda_j^2} \notin \left(\frac{1}{2}, 2\right) \\ \text{or } \frac{\epsilon_i^2}{\epsilon_j^2} \notin \left(\frac{1}{2}, 2\right), \frac{\left(\epsilon_i - \frac{\sigma\lambda_i}{2\gamma}\right)^2}{\left(\epsilon_j - \frac{\sigma\lambda_i}{2\gamma}\right)^2} \in \left(\frac{1}{2}, 2\right) \text{ and } \Phi > 0 \quad i, j = 1, 2, i \neq j \end{aligned}$$

iii) CN: Countries only cooperate on global pollutant if

$$\begin{aligned} \text{either } \frac{\epsilon_i^2}{\epsilon_j^2} \notin \left(\frac{1}{2}, 2\right), \frac{\left(\epsilon_i - \frac{\sigma\lambda_i}{2\gamma}\right)^2}{\left(\epsilon_j - \frac{\sigma\lambda_i}{2\gamma}\right)^2} \notin \left(\frac{1}{2}, 2\right) \text{ and } \frac{\left(\lambda_i - \frac{\gamma\sigma\epsilon_i}{2\eta}\right)^2}{\left(\lambda_j - \frac{\gamma\sigma\epsilon_j}{2\eta}\right)^2} \in \left(\frac{1}{2}, 2\right) \\ \text{or } \frac{\epsilon_i^2}{\epsilon_j^2} \notin \left(\frac{1}{2}, 2\right), \frac{\left(\epsilon_i - \frac{\sigma\lambda_i}{2\gamma}\right)^2}{\left(\epsilon_j - \frac{\sigma\lambda_i}{2\gamma}\right)^2} \in \left(\frac{1}{2}, 2\right) \text{ and } \Phi < 0 \quad i, j = 1, 2, i \neq j \end{aligned}$$

iv) NN: Countries always refuse to sign any agreement if otherwise.

And the equilibrium abatement levels of global pollutant are:

$$A_i = \begin{cases} \frac{2\eta\lambda_i - \sigma\epsilon_i + 2\eta\lambda_j - \gamma\sigma\epsilon_j}{4\eta - \sigma^2} & \text{if CC} \\ \frac{2\eta\lambda_i - \sigma\epsilon_i + \frac{\sigma^2}{2}\lambda_j - \gamma\sigma\epsilon_j}{4\eta - \sigma^2} & \text{if NC} \\ \frac{2\eta\lambda_i - \sigma\epsilon_i + 2\eta\lambda_j - \gamma\sigma\epsilon_j}{4\eta - \sigma^2} & \text{if CN} \\ \frac{2\eta\lambda_i - \sigma\epsilon_i}{4\eta - \sigma^2} & \text{if NN} \end{cases} \quad i, j = 1, 2, i \neq j$$

Having obtained all the possible equilibria, the negotiation outcome under each condition can be estimated. For the symmetric case where countries have the same concern on each pollutant and the case where countries regard only the general environment, the outcome is the same with the sequence aA. As for the asymmetric situation, countries have the same opinion on the global environment, but one country may care more on the local pollutant than the other. Also, I assume here that $\lambda_1 = \lambda_2 = \epsilon_1 < \epsilon_2$ and $\gamma = \eta = 1/2$. Let $\frac{\epsilon_2}{\epsilon_1} = x$, substituting parameter values and simplifying the agreement conditions yield:

Region 1:

$$CC \Leftrightarrow \begin{cases} x < \min\{\sqrt{2}, (1 - \sqrt{2})\sigma + \sqrt{2}\} & \text{if } \sigma < 1 \\ x < \min\{\sqrt{2}, (1 + \sqrt{2})\sigma - \sqrt{2}\} & \text{if } \sigma > 1 \end{cases}$$

Region 2:

$$CN \Leftrightarrow \begin{cases} \max\{\sqrt{2}, (1 - \sqrt{2})\sigma + \sqrt{2}\} < x < \frac{2-2\sqrt{2}}{\sigma} + \sqrt{2} & \text{if } \sigma < 0 \\ \max\{\sqrt{2}, (1 - \sqrt{2})\sigma + \sqrt{2}\} < x < \frac{2+2\sqrt{2}}{\sigma} - \sqrt{2} & \text{if } 0 < \sigma < 1 \\ \max\{\sqrt{2}, (1 + \sqrt{2})\sigma - \sqrt{2}\} < x < \frac{2+2\sqrt{2}}{\sigma} - \sqrt{2} & \text{if } \sigma > 1 \end{cases}$$

Region 3:

$$CC \Leftrightarrow \begin{cases} (1 - \sqrt{2})\sigma + \sqrt{2} < x < \min\{\sqrt{2}, 2 + 2\sqrt{1.5 - \sigma}\} & \text{if } \sigma < 1 \\ (1 + \sqrt{2})\sigma - \sqrt{2} < x < \min\{\sqrt{2}, 2 + 2\sqrt{1.5 - \sigma}\} & \text{if } \sigma > 1 \end{cases}$$

Region 4:

$$\begin{aligned} CN &\Leftrightarrow \sqrt{2} < x < (1 - \sqrt{2})\sigma + \sqrt{2} \text{ if } \sigma^2 < 2/3 \\ NC &\Leftrightarrow \sqrt{2} < x < (1 + \sqrt{2})\sigma - \sqrt{2} \text{ if } \sigma^2 > 2/3 \end{aligned}$$

A graph is also presented. The scale is the same with the previous plot, the only difference is that there is one more line, denoted by cross-line one. In this graph, CC which means full cooperation in both pollutant issues, lies only below the straight line $\sqrt{2}$. The negotiation outcome CN is similar with the NC in previous graph, which is between the solid, dash, cross-line and the straight line. Besides, there exist another possibility of negotiation outcome, NC, which is at the right-hand extreme where σ is very high and between the solid and cross-line.

Hence, for this agenda that countries are following to negotiate on, one result holds the same, that is, when countries have similar concerns, they can always successfully find a way to cooperate for all environmental problems. And there exist another form of negotiation outcome NC. It happens only when the correlation effect of substitute pollutants are so high, causing that abating one pollutant emits even more the other pollutant. It makes the agreement on that pollutant very irrational, hence the countries prefer to sign a treaty directly on the other pollutant, making the negotiation outcome alter from CN to NC as σ is increasing.

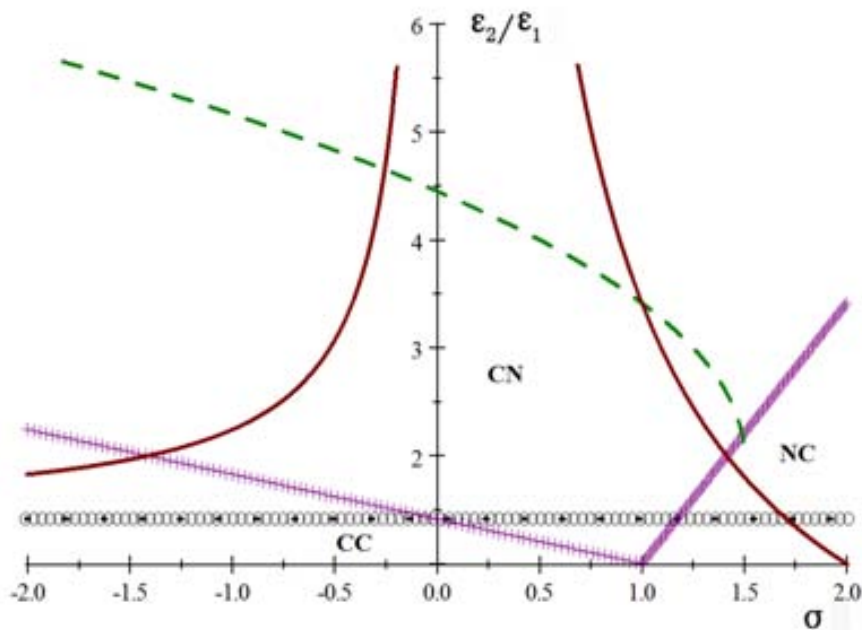


Figure 3: negotiation outcome for sequence Aa

Moreover, for the effect of the spillover γ and the cost parameter η , the results obtained in Section 2.3 also holds. That is, the lower the spillover effect of local pollutant is, the more possible that countries would cooperate. And as the relative abatement cost becomes closer and closer, the negotiation in both stages becomes easier and easier.

2.5 Comparisons of Different Negotiation Sequence

In this section I explore the outcomes of the environmental negotiations under different negotiation agenda. One can predict the negotiation outcome and abatement details in all stages, as long as the characteristic of the countries, abatement technologies and environmental nature are known. Therefore, the model can explain the countries' participation behavior in environmental agreements and why different agreement is signed by different countries.

There are four parameters, where it is impossible to exhaust all the possible outcomes. I divide all the situations into two categories, symmetric countries and asymmetric ones. In the following examples, I mainly focus on the role of the negotiation sequence, to study how the outcomes of negotiation can differ with respect to different agenda.

2.5.1 Symmetric countries

For the first category of symmetric countries, there are two dimensions of symmetry. One is that both countries have the same concern over each pollutant, but the concern between the two pollutants may not be the same: $\epsilon_i = \epsilon_j \neq \lambda_i = \lambda_j$. The other dimension of symmetry is the opposite way, that each country has the same concern over both pollutants, but the countries are concerned about the environment differently: $\epsilon_i = \lambda_i \neq \epsilon_j = \lambda_j$. I study the membership outcome under different negotiation agenda for symmetric countries, starting with the fully symmetric countries.

1. Fully symmetric countries: $\epsilon_i = \epsilon_j, \lambda_i = \lambda_j$

First, let us consider the fully symmetric case where $\epsilon_i = \epsilon_j = \lambda_i = \lambda_j$, representing that two countries are exactly the same in terms of the concern on each pollutant. Or in another sense, that two countries have the same population, hence bear the same marginal revenues. For instance, the neighboring countries of China and India, France and Italy, they all have similar concerns on the environment, and also similar populations.

If the countries are fully symmetric, the equilibrium outcome would always be a cooperation in each stage. Therefore, the sequence that they follow to discuss about the pollutants does not matter, the membership of each treaty is always the same.

This result is intuitive, when the two negotiating parties are similar, or say, have similar interests on the topic, it is more possible to reach an agreement. Not saying that they are absolutely the same, the cooperation is not a problem no matter under which sequence.

2. Countries are symmetric over each pollutant, but the concern between pollutants is different: $\epsilon_i = \epsilon_j \neq \lambda_i = \lambda_j$

If two countries are not fully symmetric $\epsilon_i = \epsilon_j \neq \lambda_i = \lambda_j$, but they have the same concerns on each pollutant, even if they may regard one pollutant much more important than the other, the equilibrium outcome would always be a successful negotiation towards an agreement. Hence, the results in the case of fully symmetric countries still hold, and the agenda of negotiation leads to the same membership.

3. Countries regard the local and global pollutants the same way but have different concerns on the environment: $\epsilon_i = \lambda_i \neq \epsilon_j = \lambda_j$

In this case every country regards the whole environment the same, irrespective of different pollutants. Though every country's concern on the environment is different, the country maintains a constant concern on different topics of environment, or say, a constant marginal revenue from pollution reduction. This is the reason why one can observe some countries, when they are active in one environmental issue, they are also active in other environmental themes. And the same for other inactive countries being always inactive.

In this case, the equilibrium outcome is: the countries can reach an agreement in both stages if $\frac{\epsilon_2^2}{\epsilon_1^2} \in (\frac{1}{2}, 2)$; otherwise non-cooperation in either stage. Hence, the agenda of negotiation does not play a role in the sense that they choose the same strategy in each stage.

Proposition 2.12 *When countries are symmetric, no matter they are fully symmetric or they have the same concern in only one dimension (the concern on each pollutant is the same for both countries or each country regards both pollutants the same), the negotiation agenda does not matter for the membership outcomes.*

For the third case, it can be interpreted in another way. Since $\epsilon_i = \lambda_i, i = 1, 2$, leaving only one parameter for the concern, and without loss of generalization the welfare function can be rewritten as:

$$W_i = A_i + A_j + a_i + \gamma a_j - \frac{1}{\lambda_i} [A_i^2 + \eta a_i^2 + \sigma A_i a_i] \quad i, j = 1, 2 \quad i \neq j$$

Comparing with the original welfare function, this one highlights the general abatement cost difference between two countries, which corresponds to a technology gap possibly existed between them. Or say, one country is more developed than the other. In this context, the two countries can represent the developed and developing countries, that the developing countries bear a much higher cost in pollution control because of the huge technology and innovation gaps.

Hence, countries only cooperate when they are similar in their abatement technology cost. Since they don't distinguish the concern on each pollutant, when they want to cooperate, they cooperate on both issues, and when they do not cooperate, the negotiation fails for all. This explains why almost in every environmental negotiations, the key friction or the hardest negotiation issue lies between the developed countries group and the developing countries group. The technology gap between them is so big that $\frac{\epsilon_2^2}{\epsilon_1^2} \notin (\frac{1}{2}, 2)$. If without technology transfer or other mechanisms, an agreement makes the developing countries worse off, it can be predicted that they always refuse to sign it. Since an agreement only with developed countries won't be enough and efficient

to fight against the global externalities, the negotiation of international environmental treaties should focus more on other mechanisms to attract the developing countries to participate.

Corollary 2.13 *Developing and developed countries cooperate only if their environmental concerns or the abatement costs are similar. When there is a large technology gap between them, the developing countries are never willing to join the agreement.*

2.5.2 Asymmetric countries

With respect to asymmetric countries, I consider that countries have different concern over one pollutant: $\epsilon_i \neq \epsilon_j, \lambda_i = \lambda_j$ (The case for $\epsilon_i = \epsilon_j, \lambda_i \neq \lambda_j$ is similar). It represents that two countries have the same opinion on the global environment, but one country may care more on the local pollutant. Such example can be considered as Switzerland and Italy, they may have similar concern on the global pollutant and both are active in Tyoto protocol, but obviously Switzerland is more concerned about the local environment and makes much more effort than Italy.

From the results obtained in Section 2.3 and 2.4, it is obvious that the equilibria for both negotiation sequences are different. Furthermore, referring to the plots which have controlled the spillover effect and abatement cost parameter, the area for countries to cooperate or not is not identical.

Proposition 2.14 *When countries are asymmetric, the negotiation sequence that countries follow in international environmental negotiations does matter, causing the membership be different under different negotiation agenda.*

This is the main result, the agenda that countries follow to discuss the agreement has an influence on the negotiation outcomes. From a social planner's point of view, a question raises naturally, which sequence can induce more membership for the agreement. The concern on the membership is the main issue under spotlight in the international

environmental agreements. Therefore, the following is going to analyze the effect of agenda by combining the negotiation outcome of two sequences together. To show the analysis in a more straightforward way, I specify the value of the correlation effect σ .

I distinguish two cases, $\sigma = 1/2$ and $\sigma = -1/2$, signifying that the pollutants are substitutes and complements, respectively. I analyze both cases in the following.

1) If $\eta = \gamma = \sigma = 1/2$, substitute the parameters, the membership outcome for the sequence aA can be obtained. Countries form coalition in both stages when $\frac{e_2}{e_1} < 1.4$, and the countries sign an agreement only in the second stage for the global pollutant when $1.4 < \frac{e_2}{e_1} < 8.2$, otherwise, no agreement formed in any stage. Countries form coalition only when they have similar interests. If countries are more and more heterogenous, they only form one agreement, which is on the global one, because $\lambda_i = \lambda_j$. When $\frac{e_2}{e_1} > 8.2$, no environmental treaty is signed in any stage.

On the other hand, if the negotiation agenda is Aa, a cooperation can be formed in both stages if $\frac{e_2}{e_1} < 1.4$. When $1.4 < \frac{e_2}{e_1} < 8.2$, countries only sign one agreement on the global pollutant in the first stage. Otherwise, in both stages countries act strategically. Hence, in this case when pollutants are substitutes, the negotiation outcome is always the same under both agendas (note that NC in sequence aA is the same with CN in sequence Aa, both from the welfare and abatement level point of view), which means that the negotiation sequence does not matter here.

2) If $\eta = \gamma = \frac{1}{2}$, $\sigma = -\frac{1}{2}$, in the sequence aA, full cooperation in all stages happens when $\frac{e_2}{e_1} < 1.4$, and when $3 < \frac{e_2}{e_1} < 4.8$. Moreover, it can happen that only one agreement signed in the second stage for global pollutant when $1.4 < \frac{e_2}{e_1} < 3$. While in the other sequence Aa where countries negotiate the global pollutant first, an cooperation in every stage is achieved when $\frac{e_2}{e_1} < 1.4$. And if $1.4 < \frac{e_2}{e_1} < 3$ countries can form an agreement on global pollutant in the first stage. The negotiation outcome under different agenda hence is not exactly the same, one can see it more clearly from the graph below. The only difference of two agenda lies in that under sequence aA, there is one more area of cooperation form. It suggests when $3 < \frac{e_2}{e_1} < 4.8$, then they can achieve cooperations in both stages for two pollutants if countries follow the agenda of negotiating local pollutant

first. On the contrary, if countries follow the negotiation sequence of Aa, negotiation leads to failure in both periods.

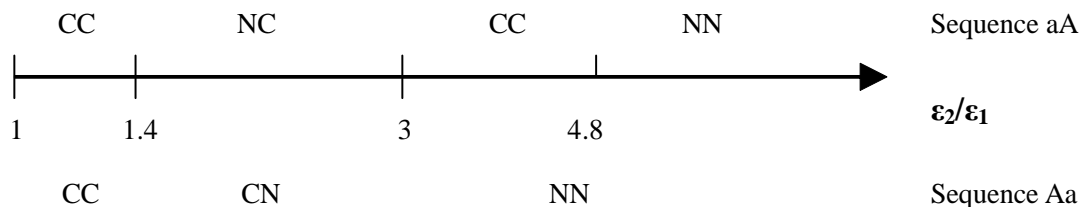


Figure 4: comparison of negotiation outcome under both sequences

Proposition 2.15 *If both countries care the same on the global pollutant and one country is more concerned on local pollutant, the negotiation agenda that first on local pollutant then on global pollutant is more possible to achieve a larger membership than the other sequence, when pollutants are complements.*

Hence, it suggests that when pollutants are complements, following the negotiation sequence aA leads to a larger membership, and subsequently, a better environmental quality. This may be due to that the local pollutant does not have much externality as the global pollutant does, which makes negotiating on an agreement on local pollutant easier than the global one. Hence, countries tend to negotiate starting from an easier issue, to show concern, reduce frictions, gain trust, etc. After that, based on the experience of the first negotiation, their second cooperation can be better facilitated.

2.6 Conclusion

In this paper I have analyzed countries' incentives to participate in international environmental agreements, taking into consideration that pollutants can be multiple and

correlated, and IEAs are negotiated sequentially. The main finding is that the agenda that countries follow to discuss their cooperation does matter from the membership perspective and the correlation between pollutants influences the negotiation outcome to a large extent. Also, as the title suggests, these two elements- the correlation between pollutants and the negotiation agenda- are the main difference of this paper from previous literature.

Firstly, there exists literature about issue linkage which links the environmental agreement with other issues, most commonly seen as trade agreements. In Barrett (1997) he emphasizes the role of trade sanction, but in Kemfert (2004) he states that restrictions on trade are not necessarily an incentive to join an coalition. The analysis in this paper goes one step further, considering the issue links within the environmental agreements by means of pollution correlations.

The existence of multiple pollutants is generally undervalued in environmental economics. However, it is important, especially when there are interactions between the pollutants. Ignoring this dimension and concentrating on each pollutant in isolation may severely bias some results in policy decisions. Unlike the previous studies on sequential coalition formations, the environmental agreements being analyzed in this paper are not exclusively separated any more, but rather correlated to each other. Such correlation can play a significant role in international environmental agreement forming process. Therefore, regarding the environmental agreements independently as only paying attention on climate change problem, or the other way around only focusing on dealing with air pollution problems may not be rational, thus biasing the long-term goals.

Secondly, regarding IEAs, the agenda problem that has been simplified in previous papers is brought forward. The main conclusion is that the sequence countries follow to negotiate on environmental problems, even though exogenous, can be essential in determining the final negotiation outcome. Under different sequences, the membership structure in each environmental treaty can be very different, this is in accordance with bargaining with agenda literature of Fershtman (1990). On one hand, this can be used by some countries to better suit their benefits, by means of proposing the preferred

negotiation agenda. On the other hand, besides technology transfer, issue leakages and threats, it can be used as another possible instrument to enlarge the memberships in IEAs. If countries' participation behavior under each sequence can be predicted, one can follow the agenda which is more environmentally beneficial and attract more countries to participate. Furthermore, the result that a successful cooperation in the first place can facilitate later negotiations has also been confirmed in the previous analysis. It can correspond both within the environmental agreement context or beyond, as political issues, financial activities and military cooperations.

Finally, some open questions remain to be studied. In this paper I considered a simple model consisting of two countries as the North-south model. It may be interesting, though to extend the analysis to more countries. In that case the spillover effect between countries may not be symmetric, that is, some countries may be positioned at downriver and suffer the damage more than others. It could be worthwhile to introduce networks into the model as well. The different locations of countries can make this problem more suitable for real life solutions. Moreover, any welfare or technological transfer between countries is not considered, hence this problem can be combined with other mechanisms used to facilitate environmental cooperations.

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Chapter 3

Optimal Delegation of Enforcement: Centralization versus Decentralization

3.1 Introduction

The environmental problem has become a more and more important issue on the government's agenda. Due to the special characteristic that the environment quality is a pure public good or local public good, it has long been debated on how to allocate powers over environmental management at different levels of government. This stream of literature is called environmental federalism, starting with Fischel (1975) and Cumberland (1979). It concentrates on whether the regulatory policy should be set by the central or local authority, among them, Oates (2001) and Dalmazzone (2006) provide a thorough review.

In the previous environmental federalism literature, it is always assumed, explicitly or implicitly, that the polluters comply with the environmental regulation. However, this may not be true. From an early study on Environmental Quality initiated by White House Council and reported in Russell (1990), it estimates that 65 percent of industrial

sources violates the air pollution limits. Thus, ignoring the compliance issue in environmental regulation is not realistic. Regarding the enforcement issues, Cohen (1999) and Heyes (2000) provide a review from the environmental aspect. In this paper, I assume that polluting firms may not comply with the regulation, thereby the enforcement is needed. Integrating the enforcement issue with the environmental federalism idea, one question arises: does the centralized-decentralized power allocation also apply to the environmental tasks such as monitoring and enforcement? Probably yes, or probably the enforcement power should be distributed to the authorities different from those that make policy decisions. Therefore, one would ask, who should do what?

The general environmental federalism literature implies that the local governments can decide on the environmental policy independently, which is not common in the real world. However, the tasks such as the enforcement are often observed on the local level. Taking the U.S. Environmental Protection Agency (EPA) for example, it is an agency under federal government in charge of the environmental policy setting and enforcing. Also, it can delegate the monitoring and enforcement responsibility to the states, through a process called authorization (including environmental program as National Pollutant Discharge Elimination System, Clean Air Act, etc.). Based on this, I assume that the environmental policies of taxation and fine are exogenous, determined ex-ante by the central government, and applied to all regions equally; while the enforcement is made endogenously by either central or local authorities. The aim of this paper is to study which level of government is optimal for environmental tasks such as monitoring, or in other words, which enforcement structure is preferred under certain conditions.

D'Amato and Valentini (2006) investigates a similar topic, with the central policy set as permit allocation. In this paper, the central environmental policies are tax related to the pollution and penalty applicable to environmental deviations. While their study may be associated to the international environment, my model corresponds more to the national situation. Besides assuming differences between central and local authority as in D'Amato and Valentini (2006), I also allow regional heterogeneity in various dimensions and a mixed enforcement structure. In addition, Lin (2006) discusses which government

should set environmental standards and meet them with policies, yet no compliance problem is studied. In van't Veld and Shogren (2012), they analyze choice of liability rules in presence of accidental pollution. Regarding empirical work, Traub and Sigman (2007) study strategic interaction between the federal and state governments, where the state with stronger environmental preferences authorize more quickly and more fully.

In the model, I consider a country comprised of two regions, with a representative firm producing in each region. Following Macho-Stadler and Pérez-Castrillo (2006) and Sandmo (2002), I assume firms choose both the actual emission and the self-report emission. To evade taxes, firms may have incentives to under-report. Correspondingly, the enforcement agency, weighing the environmental damage and economic impact, takes measure of inspection toward firms in order to detect environmental deviation. A firm is then charged with the environmental tax set by the central government, and a penalty if violation is identified. And the two enforcement structures- centralization and decentralization- are associated to whether inspection activities are determined and carried out by central or regional authorities. I start the analysis with firm's decisions of emission, compliance under inspection, as well as the optimal enforcement strategy by both central and local authorities. For the comparisons of different enforcement structure, I proceed in three dimensions: inspection probability, total welfare and regional welfare.

Pollution is public bad, hence it is intuitive to obtain that each region tends to shirk and impose a looser enforcement policy than the centralized enforcement, leading to a higher emission level in the decentralized setting. The strategic racing of enforcement is in accordance with the "race to the bottom" theory in environmental federalism, which has been studied in Conrad (1993), Gurtzgen and Rauscher (2000), and Sigman (2005) for instance. Regarding the choice of optimal enforcement set-up, comparison of total welfare is considered, where each structure has its merits hence a tradeoff exists. On one hand, the centralized enforcement internalizes the externality. On the other hand, the decentralized setting can adapt the inspection policy to the particular characteristics in that region. I find that only when the inspection effectiveness is largely heterogenous

across regions, the decentralized enforcement is preferred. However in this case, one region takes advantage of the other, increasing the gap of social welfare between two regions. Hence, it can never be a Pareto improvement with respect to the centralized enforcement if no trans-regional transfer is available.

Subsequently, I extend the model in a way that the environmental concern of the central authority is higher than the local consideration, owing to an international pressure. As they put different weights on the environment, the central and regional authorities regard the welfare from different perspectives. I show that there are cases where both the central and decentralized governments prefer the same structure, while under other circumstances they don't agree with each other on which is the optimal organization of enforcement. To be specific, if the heterogeneity in inspection effectiveness is large or the local governments barely cares about the environment, it ends up with that the central government desires the centralized enforcement while the local authority prefers the opposite. Such disagreement may lead to tensions between different level of the authorities.

In cases that decentralization can only make one region better off while harming the other, or for situations that the preferences of two governmental levels are entirely different as to the superior enforcement structure, a mixed enforcement with one region self-governed and the other under central regulation is considered. Though such structure prevails for certain environmental programs and autonomous regions, it leads to more strategic behaviors between regions.

The paper is organized as follows. The next section introduces the basic model, with the firm's problem and the optimal enforcement plan. Section 3.3 analyses the welfare comparison between centralized and decentralized enforcement. In Section 3.4, I extend the model to the case that the central authority is more concerned about the environment. Section 3.5 is another extension considering mixed enforcement. Section 3.6 summarizes the results.

3.2 The Model

3.2.1 The framework

I consider two regions, 1 and 2, belonging to a central government. The model can represent the relationship between two provinces and the central government of the country; or between two countries and a super-national organization such as the EU.

In each region there is a representative firm which emits pollution when producing. I denote by i the firm producing in region i , $i = 1, 2$, and the pollution level of firm i by e_i . I extend the existing models designed for a single country to my problem (see for example, Macho-Stadler and Pérez-Castrillo, 2006, and Sandmo, 2002). In my model, firm i 's production function takes the form: $\mu_i e_i^{1/2}$, which measures the benefits associated to the pollution. This corresponds to a situation where firm i 's production uses a technology that has emissions e_i associated to the output, and for simplicity I write the revenue in terms of emissions. Reducing the emissions associated to a given production level is costly, thereby the production function represents firm i 's gains from avoiding the cost of reducing emissions. The coefficient μ_i is used to measure the benefit of a firm: the bigger is the μ_i , the higher the private benefit of the firm from polluting is. Therefore, μ_i can be associated with the abatement cost, the incentives to adopt clean technology or the profitability of the market.

To have incentives to control emission, firms are subject to environmental regulation and are required to self-report their emissions. Self-reporting is a popular procedure used in the enforcement, as Russell (1990) states that, environmental agencies in the US require 28% of air pollution sources and 84% of water pollution source to self-report¹. I denote the reported emission as z_i , which may or may not coincide with the true one. Since there is no rewards for over-reporting emissions, the reported pollution will never be higher than the actual one: $z_i \leq e_i$. Accordingly, $(e_i - z_i)$ represents firm i 's environmental violation amount.

¹For more on the effect of self-report, consult Malik (1993), Kaplow and Shavell (1994), Livernois and McKenna (1999).

For the purpose of this paper, I distinguish environmental regulation between the design of the environmental policy, which is decided at an upper level and is exogenous for the purpose of my analysis, and the enforcement strategy that I partially endogenize.

More precisely, the environmental policy was set by central government in a previous stage of the game, and comprises of a tax rate t associated to the level of reported emissions, and a penalty rate r applicable to the evasion of the environmental taxes measured by $e_i - z_i$. Both of them are assumed to be constant.

The enforcement activity is based on an inspection strategy conducted by the responsible agency, aiming to identify a firm's actual emission and deduce its environmental violation. In the model, a firm is audited by a probability α , $\alpha \in (0, 1)$. Upon being audited, the environmental inspection is not perfect, in the sense that the true level of a firm's emission is not always identified. This imperfection can be due to the fact that pollution may be volatile, inspection may be technologically restrictive, or to other issues such as corruption or information manipulation. I define the effectiveness of the regulator's inspection as θ_i , $\theta_i \in [0, 1]$, $i = 1, 2$. The parameter θ_i represents the probability with which the firm will be caught under inspection. The lower the θ_i is, the harder the pollution is to be identified, and the less often an evasion will be caught.

Initially, a polluting firm with actual and reported emission level (e_i, z_i) should pay environmental tax associated with reported emission level tz_i to the responsible agency. Moreover, if the firm is inspected (with probability α) and being caught (with probability θ_i) cheating ($z_i < e_i$), not only the tax evaded $t(e_i - z_i)$ should be paid back, a penalty based on the violation amount $r(e_i - z_i)$ will also be charged. Therefore, a firm subject to environmental regulation I have described gets the expected profit:

$$\pi_i = \mu e_i^{1/2} - tz_i - \alpha\theta_i(t + r)(e_i - z_i)$$

In this model, pollution is a public "bad", whose associated environmental damage affects both regions. For simplicity, I assume that the pollutant is a global one (for example carbon dioxide), where the damage for each country depends on the total level of emissions $(e_1 + e_2)$. The damage function associated to the emission takes the form

$D(e_1 + e_2) = (e_1 + e_2)^2$. The convex functional form suggests that a marginal pollution brings larger damages, for instance the harm to public health and biodiversity.

Environmental regulators, no matter whether activities are performed at the central or regional level, are concerned about environmental damages. Besides, the profit of the firm is also of great interest of the governments because it affects the economic activity of the regions. This conforms to certain governmental situations, for instance, the United States symbolically signed the Kyoto Protocol without enforcing it, the main reason is that they claim "it would result in serious harm to the economy of the United States". In other words, when authorities are concerned about the environment, the most important tradeoff they take into consideration is the environmental benefit and the economic impact of the environmental policy related to the firm's activities such as profits, input markets and employment. In my model, the last term is represented by the firm's profit.

Environmental authorities weigh a combination of firm's profit and environmental damage, and they choose the inspection probability to apply to the firms (and I assume that there is perfect commitment). Depending on the governmental organization of the country, such auditing strategy can be either determined by central regulating authority or decentralized to regional enforcement agencies. If the inspection policy is determined at the centralized level, the inspection strategy is equally applied in both regions, which I denote as $\alpha^C \in [0, 1]$. If the regional authorities are in charge of the enforcement policy, they decide simultaneously their enforcement strategies and their inspection probabilities are denoted as (α_1^D, α_2^D) , with $\alpha_i^D \in [0, 1]$, $i = 1, 2$. In what follows, I will use the generic notation α when referring to the probability of an audit in any decision structure.

The timing of the game is as follows:

- First: if the enforcement structure is centralized, the central agency decides a common inspection policy α^C ; if alternatively, the enforcement is implemented by the local agencies, they simultaneously decide on their own enforcement policy

(α_1^D, α_2^D) .

- Second: firms choose their actual emission e_i , and their report of emission z_i . An environmental tax is charged by the regulating agency according to the reported emission tz_i .
- Third: the responsible agency (either the central or the regional one) implements the enforcement policy announced in stage 1 and audits the firm with probability α . If inspected, the firm i 's true emission will be identified with probability θ_i .
- Fourth: if the firm is not inspected, or no evasion is identified when inspected, then nothing happens. If the firm is audited and the inspection provides proof of noncompliance, the firm is identified as an evader and is required to pay back the evaded taxes plus the penalty, in total $(t+r)(e-z)$.

Given the sequentiality of the decisions, the game is solved by backward induction. I begin by solving the firms' decision in the third stage of the game (since in the last stage no strategic decision is made), which is common to all the structures I analyze later on.

3.2.2 Firm's decision

Given the environmental policy t and r , the enforcement probability α , a firm with parameter μ_i and θ_i chooses the actual emission e_i and reported emission z_i to maximize its profit:

$$\text{Max}_{e,z} \left[\pi_i = \mu_i e_i^{1/2} - tz_i - \alpha \theta_i (t+r)(e_i - z_i) \right] \quad i = 1, 2$$

Assumption 3.1: $0 \leq \theta_i \leq \frac{t}{t+r}$, for $i = 1, 2$.

Assumption 3.1 is made in order to simplify the analysis. It ensures an interior solution for the firms' decision problem, which means that the monitoring efficiency is not one. It follows that even the firm is audited with probability $\alpha = 1$, that is, the agency monitors all the time, still it is not optimal for the firm to report honestly.

The first order conditions of the firm's problem are:

$$\frac{\partial \pi_i}{\partial e_i} = \frac{1}{2} \mu_i e_i^{-1/2} - \alpha \theta_i (t + r) = 0$$

$$\frac{\partial \pi_i}{\partial z_i} = -t + \alpha \theta_i (t + r) = 0$$

Under Assumption 3.1, I can restrict to the following optimal decision (for complete solutions, see Macho-Stadler and Pérez-Castrillo, 2006).

Lemma 3.1 *Given policy parameters (α, t, r) , and firm characteristics (μ_i, θ_i) , a firm's optimal strategy is defined as:*

$$e_i = \left(\frac{\mu_i}{2\alpha\theta_i(t+r)} \right)^2 \quad \text{and} \quad z_i = 0$$

Accordingly, the firm's profit is:

$$\pi_i = \frac{\mu_i^2}{4\alpha\theta_i(t+r)}$$

Lemma 3.1 shows that the firm's emission decision is negatively influenced by the inspection policy α . In other words, the tougher the enforcement is, the more it deters pollution. The same effect happens for the environmental policy (t, r) and the inspection effectiveness parameter θ_i , which decrease equilibrium emission level and the firm's profit. Besides, a higher μ_i , suggesting a higher benefit of a firm from emission or a higher cost to abate pollution, encourages the firm to pollute more. As for the optimal self-report, the firm always claims clean. This is due to a relatively low efficiency level of violation detection θ_i , thereby the firm chooses to report the minimal possible level, that is, $z = 0$.

Corollary 3.2 *Under Assumption 3.1: (a) The optimal emission e_i is decreasing in the inspection probability α and in the inspection effectiveness θ_i ; and it is increasing in the benefit coefficient μ_i . (b) The report z is independent of the policy parameters.*

3.2.3 Centralized enforcement

Given the firm's reaction towards given enforcement policies, enforcement agencies determine inspection probabilities at this stage. I start with the centralized enforcement case. When a central agency decides on a uniform inspection policy to be applied to both regions, it weighs firm's profits and environmental damages from both regions in the following way:

$$W(\alpha^C) = \pi_1(\alpha^C) + \pi_2(\alpha^C) - \lambda^C(e_1(\alpha^C) + e_2(\alpha^C))^2$$

where W is the total welfare function and λ^C represents the central government's relative concern on environment over all regions.

By substituting the firm's decision functions and profits obtained in Lemma 3.1, the welfare function can be rewritten as:

$$W(\alpha^C) = \frac{\mu_1^2}{4\alpha^C\theta_1^C(t+r)} + \frac{\mu_2^2}{4\alpha^C\theta_2^C(t+r)} - \frac{\lambda^C}{[2\alpha^C(t+r)]^4} \left(\frac{\mu_1^2}{(\theta_1^C)^2} + \frac{\mu_2^2}{(\theta_2^C)^2} \right)^2$$

I will use superscript "C" to denote the centralized enforcement case, and afterwards the superscript "D" will be used for decentralized case. Similarly, as the inspection effectiveness θ can differ between central and local authority level, I denoted θ^C and θ^D , respectively, to be able to consider informational advantages or corruption issue.

From first order conditions, we obtain the result below:

Lemma 3.3 *The optimal inspection probability under the centralized enforcement structure is:*

$$\alpha^C = \frac{1}{t+r} \left(\frac{\lambda^C \left(\frac{\mu_1^2}{(\theta_1^C)^2} + \frac{\mu_2^2}{(\theta_2^C)^2} \right)^2}{\frac{\mu_1^2}{\theta_1^C} + \frac{\mu_2^2}{\theta_2^C}} \right)^{1/3}$$

The corresponding welfare is:

$$W(\alpha^C) = \frac{3}{16} \left(\frac{\left(\frac{\mu_1^2}{\theta_1^C} + \frac{\mu_2^2}{\theta_2^C} \right)^4}{\lambda^C \left(\frac{\mu_1^2}{(\theta_1^C)^2} + \frac{\mu_2^2}{(\theta_2^C)^2} \right)^2} \right)^{1/3}$$

The optimal inspection probability defined in Lemma 3.3 is increasing in the emission benefit parameter, $\frac{\partial \alpha^C}{\partial \mu_i} > 0$. The intuition is that, the higher the emission benefit (or abatement cost) is, the more incentives firms have in polluting, thereby the enforcement policy becomes more stringent to curb pollution. Moreover, $\frac{\partial \alpha^C}{\partial t} < 0$, $\frac{\partial \alpha^C}{\partial r} < 0$, $\frac{\partial \alpha^C}{\partial \theta_i} < 0$, suggesting that the enforcement strategy is complementary with respect to environmental policy and inspection effectiveness.

3.2.4 Decentralized enforcement

In the context of decentralized enforcement, where each local government cares about the profit of the firm established in his region and the pollution damage associated to his own location, both regions make their own decision simultaneously, and maximize their local social welfare:

$$W_i(\alpha_i^D) = \pi_i(\alpha_i^D) - \lambda_i(e_1(\alpha_1^D) + e_2(\alpha_2^D))^2 \quad i = 1, 2$$

W_i represents the welfare in region i and λ_i is the parameter measuring the region i 's perception of environmental damage. Note that this parameter can also be interpreted as the size of population in region i , in which a larger population will cause a bigger concern about environmental damage in the region.

After the substitution of the function of firm's decisions, regional welfare becomes:

$$W_i(\alpha_i^D) = \frac{\mu_i^2}{4\alpha_i^D \theta_i^D (t+r)} - \frac{\lambda_i}{[2(t+r)]^4} \left(\frac{\mu_1^2}{(\alpha_1^D)^2 (\theta_1^D)^2} + \frac{\mu_2^2}{(\alpha_2^D)^2 (\theta_2^D)^2} \right)^2$$

By combining the first order conditions of both regions, the Nash equilibrium vector of optimal inspection probabilities can be obtained.

Lemma 3.4 *The optimal enforcement policy under decentralized structure is the following:*

$$\alpha_i^D = \frac{1}{\theta_i^D (t+r)} \left[\lambda_i \left(\mu_i^2 + \frac{\mu_j^2 \lambda_i^2}{\lambda_j^2} \right) \right]^{1/3} \quad i, j = 1, 2 \quad i \neq j$$

Under decentralization, region i 's welfare and the total welfare is:

$$W_i(\alpha_i^D) = \frac{1}{16 \left[\lambda_i \left(\mu_i^2 + \frac{\mu_j^2 \lambda_i^2}{\lambda_j^2} \right) \right]^{1/3}} \left(3\mu_i^2 - \frac{\mu_j^2 \lambda_i^2}{\lambda_j^2} \right) \quad i, j = 1, 2 \quad i \neq j$$

$$W_1(\alpha_1^D) + W_2(\alpha_2^D) = \frac{3 \left(\frac{\mu_1^2}{\lambda_1} + \frac{\mu_2^2}{\lambda_2} \right) - \frac{\lambda_2 \mu_1^2}{\lambda_1} - \frac{\lambda_1 \mu_2^2}{\lambda_2}}{16 \left(\frac{\mu_1^2}{\lambda_1^2} + \frac{\mu_2^2}{\lambda_2^2} \right)^{1/3}}$$

Since both regions act strategically, their behaviors ignore the external effects and affect both the enforcement policy and the corresponding welfare.

To see the effects of their behavior, I first analyze how the regional governments choose their own inspection probability depending on the regional parameters. If the region j cares more about the environment, the regulating agency in region i tends to lower its monitoring probability, i.e., $\frac{\partial \alpha_i}{\partial \lambda_j} < 0$, and take advantage of the stringent enforcement policy in the other region. Such "race to the bottom" phenomena is due to two causes. On one hand, the externality, i.e., that pollution is global makes that the other region controls on emissions has the same effect as my region controlling them. On the other hand, there is a cost, since controlling pollution harms the profit of the firm. The combination of these effects leads to the fact that regions always have incentives to shirk (in the sense that it implements a looser or less frequent monitoring) if the other region takes the responsibility.

Second, as for the regional welfare, if region j cares more about the environment, region i will be better off by free-riding region j 's stringent environmental enforcement, i.e., $\frac{\partial W_i}{\partial \lambda_j} > 0$. To illustrate this point, imagine an extreme case, in which one region exclusively cares about the profit, i.e., $\lambda_j \rightarrow 0$. This leads to $\alpha_j^D \rightarrow 0$ and e_j goes to the maximum value, causing region i an important welfare loss. Furthermore, $\frac{\partial W_i}{\partial \mu_j} < 0$, suggesting that a higher benefit from emission or a higher abatement cost in region j reduces the welfare in region i . Note interestingly, the region who is more polluting harms the other one, but not himself $\frac{\partial W_i}{\partial \mu_i} > 0$.

Corollary 3.5 *When both regions act strategically, they have no incentives to internalize the negative externalities: for $i, j = 1, 2$, and $i \neq j$, (a) the optimal decentralized enforcement policy of region i is decreasing in λ_j , (b) the local welfare in region i is decreasing in μ_j , and increasing in λ_j .*

3.3 Comparisons between Centralized and Decentralized Enforcement: Case $\lambda^C = \lambda_1 + \lambda_2$

For the comparison between centralized and decentralized enforcement, I begin with the case where $\lambda^C = \lambda_1 + \lambda_2$. This case corresponds to a central government whose concern on the environment is the sum of the regional concerns, or as the addition of the population in two regions. The assumption will be relaxed in Section 3.4.

It is important to note that, on one hand, the central government has the advantage of internalizing the negative externality when they impose the centralized enforcement towards all the regions. On the other hand, the decentralized enforcement has its advantages in a way that the decentralized enforcement can account for the heterogeneity across regions, and in another way the local authorities have information, efficiency or cost advantages. Adapting to the context in this paper, it corresponds to the difference across regions in λ ($\lambda_1 \neq \lambda_2$), μ ($\mu_1 \neq \mu_2$), θ ($\theta_1 \neq \theta_2, \theta_i^C = \theta_i^D$), and the difference between central and local level, represented by θ ($\theta_1^C = \theta_2^C, \theta_1^D = \theta_2^D, \theta^C \neq \theta^D$). Therefore, a trade-off exists between both structures. The comparison of the enforcement level, as well as the welfare, depends on the relative size of these effects. In the following, I compare the two structures in three dimensions: optimal enforcement policy α^C versus (α_1^D, α_2^D) , total welfare $W(\alpha^C)$ versus $W(\alpha_1^D, \alpha_2^D)$, and local welfare $W_i(\alpha^C)$ versus $W_i(\alpha_1^D, \alpha_2^D)$.

3.3.1 Comparison of enforcement policy

The first question of consideration is whether the optimal inspection level in the decentralized structure is higher or lower than the centralized one. In other words, do the local agencies put more effort on environmental enforcement or they tend to shirk? For simplicity, I compare inspection probabilities between these two structures by varying only one parameter at the time.

Proposition 3.6 *Comparing the decentralized enforcement policy chosen by the local agencies (α_1^D, α_2^D) and the enforcement decided by the central authority α^C (with $i, j = 1, 2$ and $i \neq j$), given other parameters symmetric across regions:*

(a) *If regions have equal or very similar parameters in λ ($\frac{\lambda_i}{\lambda_j} < 1.5$) or in θ ($\frac{\theta_i}{\theta_j} < 2.2$), then $\alpha^C > \alpha_i^D$; otherwise when regions are largely asymmetric with $\frac{\lambda_i}{\lambda_j} > 1.5$ or $\frac{\theta_j}{\theta_i} > 2.2$, then $\alpha^C < \alpha_i^D, \alpha^C > \alpha_j^D$.*

(b) *Unless the central government is much more effective in detecting environmental violations than the regions ($\frac{\theta^C}{\theta^D} > \sqrt[3]{2}$) which leads to $\alpha^C < \alpha_i^D, i = 1, 2$, the centralized enforcement is always more stringent than the decentralized one.*

If regions are fully symmetric, a lower inspection probability is applied by local authorities than central government due to the fact that central regulation can internalize externalities. As both regions shirk in environmental enforcement, it naturally induces a higher total pollution level.

If regions are asymmetric, for instance there is a difference in the environmental concern or population among regions, $\lambda_i \neq \lambda_j$. The region who is more concerned about the environment imposes a more frequent inspection, while the other region does the opposite. As the difference becomes large enough, i.e., $\frac{\lambda_i}{\lambda_j} > 1.5$, the region more concerned about the environment imposes a more stringent enforcement even than the central agency. Such trend also applies to the heterogeneity in inspection effectiveness θ . The region whose inspection technology is less effective or whose pollution is more volatile (θ_i smaller) chooses a higher monitoring probability.

As for the monitoring difference between central and regional agency, the decentralized decisions are either higher (if $\frac{\theta^C}{\theta^D} > \sqrt[3]{2}$) or lower ($\frac{\theta^C}{\theta^D} < \sqrt[3]{2}$) than the centralized enforcement for both regions. For instance, if the local government has more information on their own firms, they both decrease their inspection frequency in decentralized structure. Alternatively, if there is more corruption in the regional level corresponding to $\frac{\theta^C}{\theta^D} > \sqrt[3]{2}$, the local agencies implement a tougher enforcement strategy.

To sum up, when local governments determine their local enforcement strategy, at least one region- if not both- chooses a lower inspection probability α_i^D than the centralized enforcement policy α^C , except in the case that both regions have much lower monitoring effectiveness, i.e, $\frac{\alpha_i^D}{\alpha^C} > 1 \Leftrightarrow \frac{\theta^C}{\theta^D} > \sqrt[3]{2}$.

3.3.2 Comparison of total welfare

Knowing how the enforcement policy under centralized and decentralized case compares, a next question that can be brought forward is which environmental enforcement structure or under which conditions such structure is preferred. This is a key point concerning the evaluation of different enforcement settings, and it is measured by total welfare of all regions. Given one enforcement structure yielding higher total welfare than the other, more support is gained and such policy can be elected without rejection if one prior stage exists for endogenous policy choice.

In my model, total welfare can be defined from two different perspectives: the central agency view point and the regional one. In this section where $\lambda^C = \lambda_1 + \lambda_2$, total welfare is uniquely defined since $W = W_1 + W_2$, specifically $W(\alpha^C) = \sum_{i=1}^2 W_i(\alpha^C)$ and $W(\alpha_1^D, \alpha_2^D) = \sum_{i=1}^2 W_i(\alpha_i^D)$. Note that the total welfare in the decentralized setting is simply the sum of regional welfare of these two regions, and the comparison between two settings is carried out by focusing on one parameter each time with other characteristics symmetric between regions.

Proposition 3.7 *Comparing total welfare in the centralized and decentralized enforcement set-ups, the total welfare under centralized enforcement is always higher, except*

when there's a big difference in monitoring effectiveness ($\frac{\theta_i}{\theta_j} > 3.4$, $\lambda_1 = \lambda_2$, $\mu_1 = \mu_2$, $\theta_i^C = \theta_i^D = \theta_i$, $i, j = 1, 2$, $i \neq j$) across regions which leads to $W(\alpha_1^D, \alpha_2^D) > W(\alpha^C)$.

When there is a big difference in the probability of a firm being caught when audited, it is optimal to delegate the environmental enforcement to the local authorities. Note that the heterogeneity across regions required to reverse the pro-centralized enforcement result is not small, suggesting that only a large effectiveness advantage in the local level can beat the advantage in centralized structure of internalizing the externality. Another result is that, as long as $\lambda^C = \lambda_1 + \lambda_2$, the level of λ_1 and λ_2 do not matter in the comparison: the centralized enforcement is always more profitable.

3.3.3 Comparison of local welfare W_i

Given that there exist cases where the decentralized enforcement is superior, would it be the case that both regions are better off? Or one is taking advantage of the other? In other words, I want to study whether both regions have incentives to apply for the enforcement delegation or are there conflicts between them? If no compensation or subsidy across regions is available, decentralized environmental enforcement which makes only one region better off while the other worse off from centralized structure is never a pareto improvement, thereafter such changes may not be attractive.

Proposition 3.8 *Changing from centralized environmental enforcement to decentralized one, it can never be a Pareto improvement for both regions (controlling for other parameters): if large heterogeneity exists in λ ($\frac{\lambda_i}{\lambda_j} > 1.18$), μ ($\frac{\mu_i}{\mu_j} > 2.04$), or θ ($\frac{\theta_i}{\theta_j} > 3.1$) across regions, region i is better off while region j suffers; otherwise both regions end up with lower welfare under decentralized structure ($i, j = 1, 2$, $i \neq j$).*

Even under the condition $\frac{\theta_i}{\theta_j} > 3.4$ that leads total welfare higher for decentralized enforcement, it benefits one region while harming the other, since such condition cannot be satisfied for both regions. As a result, if there's a big difference across regions, the welfare in the region with the lower concern about the environment (λ), the higher

abatement cost in production (μ), or the more effective in inspection (θ), increases comparing to what the region can obtain from centralized enforcement, while the other region suffers. In such cases, without transfer or subsidy across regions, one of the regions would oppose the idea of the decentralized enforcement.

To sum up, the heterogeneity effect can in some circumstances make the decentralized enforcement structure more preferable from a global point of view, i.e. $W(\alpha_1^D, \alpha_2^D) > W(\alpha^C)$. Yet, changing from a centralized setting to delegating the environmental enforcement never consists a Pareto optimal (if transfers are not possible).

3.4 Extension: Comparison between Centralized and Decentralized Enforcement: Case $\lambda^C > \lambda_1 + \lambda_2$

In this section, I relax the assumption of $\lambda^C = \lambda_1 + \lambda_2$ to consider the case where $\lambda^C > \lambda_1 + \lambda_2$, which allows to take into account the fact that the central government's concern about the environment may be higher than the sum of the local concerns. This can be understood as a central authority putting more weight on the environment due to a more harmonious concern within the national level, or owing to a big pressure from the international community. As a result, the environmental problem is treated with priority on the central authority's agenda comparing to local governments.

This section analyzes whether different agenda for central and regional government would affect our previous conclusions. In other words, would such divergence of concerns affect the comparison of the centralized and decentralized enforcement? Given the assumption $\lambda^C > \lambda_1 + \lambda_2$, the total welfare can be defined in different dimensions. In order to avoid confusion, the comparison is performed in two ways.

(1) Central authority's perspective: $W(\alpha^C)$ versus $W(\alpha_1^D, \alpha_2^D)$. The former expression is the total welfare under centralized enforcement defined in section 3.2.3, while the latter is the welfare under decentralized decisions but with the central agency's concern

of λ^C . To be specific,

$$W(\alpha_1^D, \alpha_2^D) = \sum_{i=1}^2 \pi_i(\alpha_i^D) - \lambda^C (e_1(\alpha_1^D) + e_2(\alpha_2^D))^2$$

This comparison corresponds to the central authority's evaluation on both centralized and decentralized structure, with the same agenda on the environment λ^C .

(2) Local authorities' perspective: $\sum_{i=1}^2 W_i(\alpha^C)$ versus $\sum_{i=1}^2 W_i(\alpha_i^D)$. The first expression is the sum of regional welfare under centralized enforcement, associated to the local authorities' concerns λ_1, λ_2 , i.e.,

$$\sum_{i=1}^2 W_i(\alpha^C) = \sum_{i=1}^2 \pi_i(\alpha^C) - \sum_{i=1}^2 \lambda_i (e_1(\alpha^C) + e_2(\alpha^C))^2$$

The second expression is the sum up of the regional welfare under decentralized setting. This comparison is the local governments' evaluation on both centralized and decentralized enforcement, with their own considerations for the environment (λ_1, λ_2) .

Besides considering asymmetries in inspection effectiveness with $\theta_1 \neq \theta_2$, $\theta_i^C = \theta_i^D$, I assume that the regions are symmetric in environmental concern $\lambda_1 = \lambda_2 = \lambda_0$ ($\lambda^C > 2\lambda_0$) and in pollution benefit (or abatement cost) $\mu_1 = \mu_2$.² In such way, the following comparison can be concentrated more on the tradeoff between parameters λ and θ .

When $\lambda^C > \lambda_1 + \lambda_2$, the comparison of inspection probability α is similar with the case $\lambda^C = \lambda_1 + \lambda_2$. In the following, I then compare the welfare from both the central and local authorities' view point, respectively.

Let's start with the central government perspective case. $W(\alpha^C)$ comes from Lemma 3.3, and I compute $W(\alpha_1^D, \alpha_2^D)$ according to the equation provided before, which yields:

$$W(\alpha_1^D, \alpha_2^D) = \frac{4 \left(\frac{\mu_1^2}{\lambda_1} + \frac{\mu_2^2}{\lambda_2} \right) - \lambda \left(\frac{\mu_1^2}{\lambda_1} + \frac{\mu_2^2}{\lambda_2} \right)}{16 \left(\frac{\mu_1^2}{\lambda_1} + \frac{\mu_2^2}{\lambda_2} \right)^{1/3}}$$

²In this case, considering asymmetries in μ across regions always makes the centralized enforcement preferable, which is a result already known.

Proposition 3.9 *Given $\lambda^C > \lambda_1 + \lambda_2$ and $\lambda_1 = \lambda_2$, $\mu_1 = \mu_2$, $\theta_1 \neq \theta_2$, from the central authority's point of view, only in the case that the heterogeneity in the θ ($\theta_i \neq \theta_j$) is large and λ_0 is close to λ will the decentralized enforcement be preferred.*

When the central authority is comparing the alternative of the centralized and decentralized enforcement, evidently, the condition required for a decentralized structure being preferred is relatively strict. Except in cases where (a) there is a large heterogeneity in inspection effectiveness between regions and (b) the local concern on the environment is high, the central government always prefers the centralized enforcement towards both regions.

As for the local authorities' evaluations, I first calculate the sum of the welfare under centralized enforcement from a local region's point of view, i.e., $\sum_{i=1}^2 W_i(\alpha^C)$. Substituting the α^C from Lemma 3.3, the welfare under centralized enforcement can be written as:

$$\sum_{i=1}^2 W_i(\alpha^C) = \frac{\left(\frac{\mu_1^2}{\theta_1} + \frac{\mu_2^2}{\theta_2}\right)^{4/3} \left(4 - \frac{\lambda_1 + \lambda_2}{\lambda^C}\right)}{16 \left(\frac{\mu_1^2}{\theta_1^2} + \frac{\mu_2^2}{\theta_2^2}\right)^{2/3} (\lambda^C)^{1/3}}$$

Total welfare under decentralized enforcement was obtained from Lemma 3.4. The comparison of the two regions is the following.

Proposition 3.10 *Given the parameter $\lambda^C > \lambda_1 + \lambda_2$ and $\lambda_1 = \lambda_2$, $\mu_1 = \mu_2$, $\theta_1 \neq \theta_2$, from the local authority's point of view, centralized enforcement is preferred except in cases where the heterogeneity over θ is large, and the local concern on the environment is either high or low comparing to the central one.*

Comparing the results obtained with the one obtained from the central perspective, the set of parameters for which decentralized enforcement being favorable is bigger. Besides that the conditions which induce the central government to prefer the decentralized enforcement are also satisfied, the local authorities also prefer to self-enforce when they have a lower concern on the environment. This corresponds to the intuition

that local authorities desire more of the decentralization, while the central one tend to prefer centralized regulation.

Figure 1 helps to see more clearly how the central and local agency's preferences of enforcement structure are different.

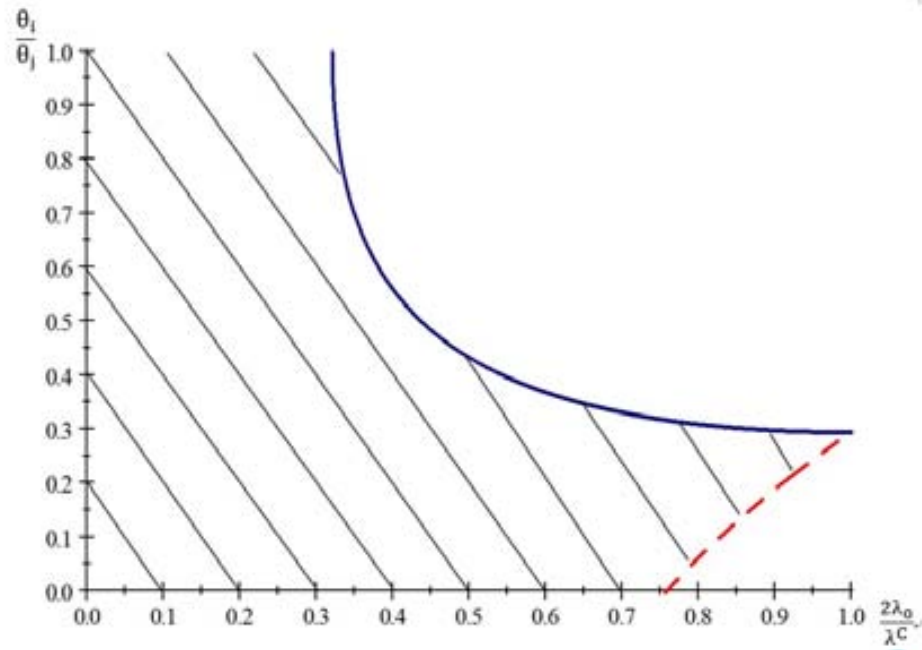


Figure 1: Central and local authority's preferences of enforcement structure

X-axis and y-axis represent $\frac{2\lambda_0}{\lambda^C}$ and $\frac{\theta_i}{\theta_j}$, respectively. The variable $\frac{2\lambda_0}{\lambda^C}$ is the relative ratio of environmental concern between local and central organization. By definition that $\lambda_1 = \lambda_2 = \lambda_0$ and $\lambda_1 + \lambda_2 < \lambda^C$, $\frac{2\lambda_0}{\lambda^C}$ ranges between 0 and 1. The ratio $\frac{\theta_i}{\theta_j}$ represents the heterogeneity in inspection effectiveness across regions, suggesting that the regions are more and more asymmetric as $\frac{\theta_i}{\theta_j}$ goes from 1 to 0.

The dash curve corresponds to the central government's preferences towards centralization or decentralization, while the solid line represents the evaluation of the local authority (corresponding expressions can be found in the appendix). One can infer that the right side of the dash curve corresponds to the situation that the central government prefers the decentralized enforcement, which only happens when there is a big

heterogeneity in $\frac{\theta_i}{\theta_j}$ and $\frac{2\lambda_0}{\lambda^C}$ is relatively high. For the solid curve of the local authority's preference, the left side of the curve indicates the favor of decentralized enforcement.

The preferences of both central and local agencies toward environmental enforcement structure obviously do not coincide. More precisely, for the right side of the solid curve both levels of governments prefer the centralized enforcement while for the right side of the dash line, both regard decentralization as a superior structure. In these two cases, consensus is gained. The rest of the region in the graph, which is shadowed, corresponds to the case that the central agency wants to impose centralized enforcement, while the local agencies prefer decentralization (note that there does not exist the case where central agency prefers decentralization while the local desires centralized enforcement). This situation appears when either the heterogeneity in θ is large enough or $\frac{2\lambda_0}{\lambda^C}$ is relatively low, suggesting that local agencies put much less weight on the environmental concern. In such occasions, if a prior period exists which serves for endogenously deciding enforcement structure, neither enforcement setting would be agreed upon. As a result, without effective negotiation, it may lead to tensions on different levels of enforcement organization, which may further induce higher non-compliance, more counter actions, or even bigger problems.

Corollary 3.11 *If the heterogeneity in inspection effectiveness θ is large or if local authorities environmental concern λ_0 is very low, then disagreement occurs in the sense that the central agency prefers the centralized enforcement while local ones favors decentralization.*

3.5 Extension: Combination of Centralized and Decentralized Enforcement

In previous sections, the analysis was focused on the choice between centralization and decentralization of environmental enforcement. Under certain conditions, a superior enforcement set-up can be approved by both governmental levels while in other circum-

stances neither centralization nor decentralization is the optimal decision for all. In this section, instead of concentrating on exclusive choices between these two enforcement settings, I take into consideration a mixed structure, that is, a combination of centralized and decentralized enforcement. Such structure widely exists for certain regulatory activities³ or countries who have autonomous regions⁴, where these regions are delegated with decentralized power and the rest of the country is under centralized regulation. The question I want to address is, when both central and local authorities are participating in the enforcement activities, would their behavior change? Hence, this section aims to explore the enforcement strategies chosen under the mixed enforcement setting, as well as its comparisons with pure centralization and decentralization case.

3.5.1 Optimal enforcement strategy

Name the autonomous and non-autonomous region of the country as region 1 and 2, respectively. The region 1 who has autonomous power determines its enforcement strategy denoted as α^{SD} . The other region, whose environmental enforcement is implemented by the central agency, applies the inspection probability denoted as α^{SC} .

I start with the optimal inspection probability for region 1 who is delegated with the enforcement power. Knowing both firms' decisions of emission, the regulating authority of the autonomous region determines α^{SD} to maximize its welfare:

$$\begin{aligned} W_1(\alpha^{SD}) &= \pi_1(\alpha^{SD}) - \lambda_1(e_1(\alpha^{SD}) + e_2(\alpha^{SC}))^2 \\ &= \frac{\mu_1^2}{4\alpha^{SD}\theta_1(t+r)} - \frac{\lambda_1}{[2(t+r)]^4} \left(\frac{\mu_1^2}{(\alpha^{SD})^2\theta_1^2} + \frac{\mu_2^2}{(\alpha^{SC})^2\theta_2^2} \right)^2 \end{aligned}$$

Note that region 1's optimal decision also depends on the other region's behavior. For region 2, the environmental regulation is enforced by the central authority. Thus from a central government's point of view, it does not only care region 2 which is in his

³For instance, the Environmental Protection Agency (EPA) in the United States delegated the enforcement activities to some states while other states still remain the jurisdiction of EPA for the National Pollutant Discharge Elimination System (NPDES) program.

⁴Examples include, the autonomous region of Pais Vasco in Spain, Quebec in Canada, etc.

control, but is also concerned about the autonomous region. Its objective function is thereby written as:

$$\begin{aligned} W_2(\alpha^{SC}) &= \pi_2(\alpha^{SC}) - \lambda_2(e_1(\alpha^{SD}) + e_2(\alpha^{SC}))^2 + \gamma [\pi_1(\alpha^{SD}) - \lambda_1(e_1(\alpha^{SD}) + e_2(\alpha^{SC}))^2] \\ &= \frac{\mu_2^2}{4\alpha^{SC}\theta_2(t+r)} + \frac{\gamma\mu_1^2}{4\alpha^{SD}\theta_1(t+r)} - \frac{\lambda_2 + \gamma\lambda_1}{[2(t+r)]^4} \left(\frac{\mu_1^2}{(\alpha^{SD})^2\theta_1^2} + \frac{\mu_2^2}{(\alpha^{SC})^2\theta_2^2} \right)^2 \end{aligned}$$

where γ measures how much the autonomous region is of the central authority's concern, and it can be either positive or negative. In fact, the fully decentralization of environmental enforcement is a special case of this combined structure with $\gamma = 0$. Combining the first order conditions of these two maximization problem, the following outcome can be obtained.

Lemma 3.12 *When centralized and decentralized environmental enforcement coexist, their optimal inspection probabilities are the following.*

$$\begin{aligned} \alpha^{SC} &= \left[\left(\frac{\mu_2\lambda_1}{\lambda_2 + \gamma\lambda_1} \right)^2 + \mu_1^2 \right]^{1/3} \frac{\lambda_2 + \gamma\lambda_1}{\lambda_1^{2/3}\theta_2(t+r)} \\ \alpha^{SD} &= \left[\left(\frac{\mu_2\lambda_1}{\lambda_2 + \gamma\lambda_1} \right)^2 + \mu_1^2 \right]^{1/3} \frac{\lambda_1^{1/3}}{\theta_1(t+r)} \end{aligned}$$

Besides, $\alpha^{SC} > \alpha^{SD}$ iff $\frac{\lambda_2}{\lambda_1} + \gamma > \frac{\theta_2}{\theta_1}$.

Note that when two regions are symmetric, the comparison between the enforcement structures depends on γ . If the central government cares about the autonomous region, i.e. $\gamma > 0$, the centralized enforcement is more stringent than the decentralized one. Otherwise, in the case that γ is negative, the autonomous region implements a more frequent inspection. Hence, the region who cares less tends to free-ride the other region through a looser enforcement plan.

When regions are asymmetric, the centralized inspection probability is higher than the decentralized one when the ratio of environmental concern $\frac{\lambda_2}{\lambda_1}$ plus the central agency's extra concern γ exceeds the ratio of inspection effectiveness between two regions $\frac{\theta_2}{\theta_1}$. Thus, if the central government does care about the welfare of the autonomous

region ($\gamma > 0$), only when the autonomous region highly values the environment but is inefficient in violation detection which makes the ratio of inspection effectiveness much higher than the ratio of environmental concern, the decentralized enforcement would be more stringent.

3.5.2 Comparison with fully centralized and decentralized enforcement

Obviously the optimal inspection probabilities in the mixed enforcement setting do not coincide with that under fully centralized or decentralized enforcement in section 3.2.3 and 3.2.4. In the following, the analysis aims to study how the optimal enforcement strategies in different structures compare. Specifically, would the inspection be more frequent or regions act more strategically when centralized and decentralized enforcement coexist? The comparison depends on the extent of the central government's concern on the development of the autonomous region (γ) and is discussed in detail below.

If $\gamma = 0$, recall that in this case the mixed enforcement structure coincides with fully decentralized setting, that is, $\alpha^{SC} = \alpha_2^D$ and $\alpha^{SD} = \alpha_1^D$. Note that the parameter γ aggravates the strategic behavior between regions, causing $\frac{\partial \alpha^{SC}}{\partial \gamma} > 0$ while $\frac{\partial \alpha^{SD}}{\partial \gamma} < 0$. Hence, when $\gamma < 0$, $\alpha^{SC} < \alpha_2^D$ and $\alpha^{SD} > \alpha_1^D$. It translates to the situation when the development of the autonomous region negatively affects the region under central control, region 2 applies an enforcement strategy even looser than the fully decentralized case while the autonomous region bears more responsibility. Conversely, when the central government cares about region 1 with $\gamma > 0$, it results in $\alpha^{SC} > \alpha_2^D$ and $\alpha^{SD} < \alpha_1^D$.

If $\gamma = 1$, the central government weighs both regions equally. Notice that this situation is not the same with the full centralization setting, because the enforcement policy applies only to one region, and there is strategic behavior between centralized and decentralized enforcement. Let me consider the case where both regions utilize the same inspection technology, and hence there is no difference in auditing effectiveness

($\theta_1 = \theta_2$). Then the central agency applies a more stringent enforcement in a mixed setting than in the fully centralized case, that is, $\alpha^{SC} > \alpha^C$ (it also holds true when $\gamma > 1$). Recall that a very low inspection probability is imposed in the autonomous region when $\gamma > 0$. Together with $\alpha^{SC} > \alpha^C$, it shows a stronger strategic interaction between both regions, or say, between the centralized and decentralized enforcement in these regions.

If $\gamma \in (0, 1)$, either outcome of $\alpha^{SC} > \alpha^C$ or $\alpha^{SC} < \alpha^C$ is possible. Moreover, there exists a value γ^* which lines the boundary leading to $\alpha^{SC} = \alpha^C$. In a mixed enforcement setting, the central government implements the same enforcement strategy with the fully centralized case yet is associated to a concern on the autonomous region less than 1 ($\gamma^* < 1$). Comparing to the total centralization where both regions are implemented with equal inspection α^C , it turns out that in the mixed setting, region 2 applies the same with $\alpha^{SC} = \alpha^C$ while the autonomous region shirks through a much lower inspection probability $\alpha^{SD} < \alpha_1^D$.

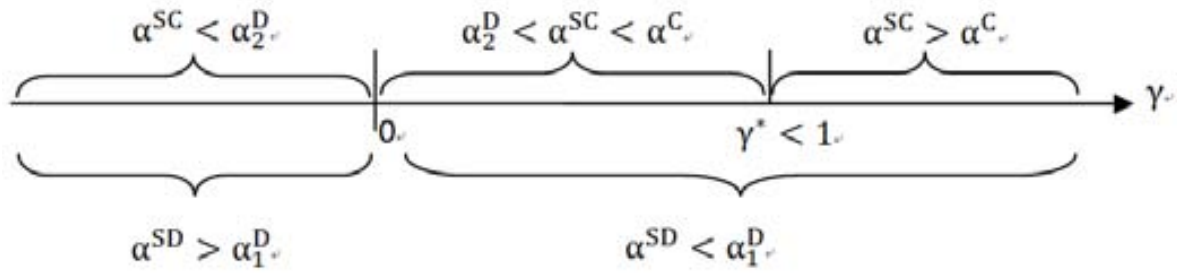


Figure 2: Comparison between fully centralized/decentralized enforcement and mixed structure with $\theta_1 = \theta_2$

The figure above summarizes previous discussions. Recall that section 3.3.3 concludes that even if decentralization is preferred by centralized enforcement, it can never be that both regions are better off. If the mixed enforcement setting is feasible, it seems reasonable for the region who benefits from the decentralization to adopt such structure, while the other region who suffers from decentralized enforcement remains in the jurisdiction of the central authority. However, from the analysis in this section, we learn that

the region under decentralized enforcement implements a less frequent inspection than what he would do under a pure decentralization situation ($\alpha^{SD} < \alpha_1^D$) if $\gamma > 0$. In other words, this region tends to shirk under this mixed enforcement set-up, by relying on a more stringent centralized enforcement of the other region. Therefore, when one region is under central control while the other region has the enforcement power delegated, one can expect to see more serious strategic behavior and free-rider problem to arise.

3.6 Conclusion

In this paper, I have analyzed firms' compliance behavior toward environmental regulation and the optimal enforcement strategy under centralized, decentralized and mixed enforcement set-up. A comparison between these structures is presented, from both perspectives of enforcement policy and welfare. I show which level of the government is optimal to take on the enforcement responsibility under certain conditions. The results can account for different situations and parameters, including monitoring cost, inspection information, different concern on environment from organizational levels, corruption issues, clean technology status, and so on.

The coexistence of central and local environmental regulation has raised attention in previous literature. Most of research considers a centralized permit market, together with a local subsidy, penalty, or energy tax as in Eichner and Pethig (2010), Santore, Robison and Klein (2001), Brechet and Peralta (2007), respectively. They conclude that the local strategic behavior conflicts with the central system which results in inefficiency. In my paper, besides looking into the free-riding problem in the decentralized system, I take into account the possibility of choosing the regulatory structure- managed by either central or local authorities.

From a general perspective, previous research on how to distribute power- other than environmental enforcement- between levels of government has focused on the tradeoff between internalization of externality and central versus local preferences. In my model, I also include this tradeoff by considering a different concern on the environment be-

tween central and local authority. I conclude that this difference in preferences can in some circumstances result in a superior enforcement set-up supported by both levels of governments, while in other cases neither centralization nor decentralization would be agreed upon. Continuing with the disagreement arisen between central and local governments, there is a potential risk existing in many international environmental agreements. Taken Kyoto protocol for example, even if countries initially participate under the agreement, it may not provide sufficient incentives for their compliance. As stated in Aldy and Stavins (2008), the top-down architectures based on multilateral agreements on targets and timetables, may not provide robust incentives for participation and compliance. And such lack of enforcement would to a large extent result in a regulation failure. Hence, the analysis in this paper implies that for the regulation to be more effective, the policy design later should pay more attention on the national and regional institutions.

Beside this tradeoff, I have studied other effects. The main advantage of decentralized enforcement is that if regions are heterogeneous, the central government cannot account for different characteristics in regions by applying equal inspection strategy. Hence, the centralized enforcement is favored unless the heterogeneity between regions is big enough, especially in the auditing effectiveness. With respect to the enforcement policy, regions behave in line with "race to the bottom" phenomenon under decentralized enforcement. However in the mixed enforcement structure where one region is delegated with enforcement power and the other region is under central jurisdiction, more free-rider and strategic behavior are foreseen.

Note that the result in this paper can be generalized to other concave production function and convex damage functions. Throughout my model firms are assumed to be risk-neutral. Extending the model to risk-averse firms should not change the result as shown in Sandmo (2002). Besides, I did not consider endogenous inspection probability that may depend on the reported or actual emission. By doing so, the distribution function of monitoring probability would be discontinuous and complicate the model tremendously. A more general enforcement can be found in Macho-Stadler and Pérez-

Castrillo (2006), and Franckx (2005) in which they consider an endogenous ambient monitoring. Further, I assume that the environmental policy is set by the central government. One possible extension of the analysis is to take into consideration "conjoint federalism", that is, both the local and central governments can decide on the environmental policy and enforcement. As in the paper of Lin (2006), she finds that the local governments choose standards while the central one meets the standard is the most efficient form.

Though I apply my model to regulation in particular to the environmental theme, the implications of my model can be generalized to other federalism choice with interjurisdictional externalities. Take the patent and copyright problem for example, it shares some common features with the environmental regulation. There is law requiring people to respect the copyright, which can be regarded as the central policy. But in fact, only some countries comply with it, leading to an unbalanced enforcement and inducing further problems. This also happens in some education policies and other regulations, which may deserve further investigation.

3.7 Appendix

3.7.1 Proof of Proposition 3.6

Proof. Note that, by using the values of α_1^D , α_2^D , and α^C from Lemma 3.3 and 3.4, it can be defined that

$$\frac{\alpha^C}{\alpha_i^D} = \left(\frac{(\lambda_1 + \lambda_2) \left(\frac{\mu_i^2}{(\theta_i^C)^2} + \frac{\mu_j^2}{(\theta_j^C)^2} \right)^2}{\frac{\mu_i^2}{\theta_i^C} + \frac{\mu_j^2}{\theta_j^C}} \right)^{1/3} \frac{\theta_i^D}{\lambda_i^{1/3} \left((\mu_i^2 + \frac{\mu_j^2 \lambda_i^2}{\lambda_j^2}) \right)^{1/3}} \text{ for } i, j = 1, 2, i \neq j \quad (3.1)$$

First, I start with fully symmetric situation: $\lambda_1 = \lambda_2$, $\mu_1 = \mu_2$, $\theta_i^k = \theta_j^m$, with $i, j = 1, 2$ and $k, m = C, D$. In this case (3.1) gives the following, with centralized inspection probability higher than the decentralized one.

$$\frac{\alpha^C}{\alpha_i^D} = \sqrt[3]{2} > 1, \text{ for } i, j = 1, 2, i \neq j.$$

Second, I consider regions that differ in λ , that is, $\lambda_1 \neq \lambda_2$, suggesting the two regions are different in their population or their concern of the environment, with all other parameters the same, $\mu_1 = \mu_2$, $\theta_i^k = \theta_j^m$, with $i, j = 1, 2$ and $k, m = C, D$.

Cancelling the common terms, (3.1) simplifies to $\left(\frac{1 + \frac{\lambda_1^2}{\lambda_2^2}}{2(1 + \frac{\lambda_2}{\lambda_1})} \right)^{1/3}$. Taking $\frac{\lambda_1}{\lambda_2}$ as a variable, it turns out that $\frac{\alpha^D}{\alpha^C} > 1 \Leftrightarrow \frac{\lambda_1}{\lambda_2} > 1.5$. In words, when $\frac{\lambda_i}{\lambda_j} > 1.5$, $i, j = 1, 2, i \neq j$, region i 's enforcement policy is more stringent than the central one, while the other region is looser. Conversely, if $\frac{\lambda_i}{\lambda_j} < 1.5$, both regions will impose a lower inspection probability than α^C .

Third, if regions differ only in the parameter μ . It turns out that the centralized enforcement is always more stringent due to the specific functional form I apply here.

$$\frac{\alpha^C}{\alpha_i^D} = \left(\frac{2\lambda_i(\mu_1^2 + \mu_2^2)}{\lambda_i(\mu_1^2 + \mu_2^2)} \right)^{1/3} = \sqrt[3]{2} > 1, \text{ for } i = 1, 2$$

Finally, I concentrate on inspection effectiveness θ . Since there are four different θ , i.e., θ_1^C , θ_2^C , θ_1^D , θ_2^D , for simplicity, I consider two cases. One focuses on the difference

between regions: $\theta_i^C = \theta_i^D$, $i = 1, 2$, but $\theta_1 \neq \theta_2$, which represents a regional difference in inspection effectiveness. The result obtained is similar with the effect of environmental concerns where only a large heterogeneity can cause one regional authority to apply a more stringent enforcement strategy, $\frac{\alpha_1^D}{\alpha^C} > 1 \Leftrightarrow \frac{\theta_2}{\theta_1} > 2.2$. The other asymmetry lies between the central agency and local authorities with regions symmetric: $\theta_1^C = \theta_2^C$ and $\theta_1^D = \theta_2^D$ but $\theta_i^C \neq \theta_i^D$. This can correspond to the situation that more bribery from the polluting firms in the local level makes the central government more effective or the local authority has more information on the pollution status of his region, thereby more efficient. The rasion (3.1) simplifies to $\frac{\alpha^D}{\alpha^C} = \frac{\theta^C}{\sqrt[3]{2}\theta^D}$, which gives $\frac{\alpha_i^D}{\alpha^C} > 1 \Leftrightarrow \frac{\theta^C}{\theta^D} > \sqrt[3]{2}$. ■

3.7.2 Proof of Proposition 3.7

Proof. I start with the symmetric case. If both regions are fully symmetric in all the parameters, the total welfare of the centralized structure is at least as high as that of the decentralized setting simply because the central enforcement α^C is set to the value that maximizes $W(\alpha)$. Hence, for $\lambda_1 = \lambda_2$, $\mu_1 = \mu_2$, $\theta_i^k = \theta_j^m$, with $i, j = 1, 2$ and $k, m = C, D$, one would have $W(\alpha_1^D, \alpha_2^D) \leq W(\alpha^C)$.

Second, if all other parameters are equal, only with differences in λ , i.e., $\lambda_1 \neq \lambda_2$. After canceling the common terms, the expression $\frac{W(\alpha_1^D, \alpha_2^D)}{W(\alpha^C)}$ which is derived from Lemma 3.3 and 3.4 can be simplified to:

$$\frac{W(\alpha_1^D, \alpha_2^D)}{W(\alpha^C)} = \frac{\left(1 + \frac{\lambda_2}{\lambda_1}\right)^{1/3} \left(3 + \frac{3\lambda_1}{\lambda_2} - \frac{\lambda_2}{\lambda_1} - \frac{\lambda_1^2}{\lambda_2^2}\right)}{3 \cdot 2^{2/3} \left(1 + \frac{\lambda_1^2}{\lambda_2^2}\right)^{1/3}}$$

Taking $\frac{\lambda_1}{\lambda_2}$ as one variable, the value of the expression above is always smaller than 1, with the maximum value achieved at $\lambda_1 = \lambda_2$. Hence, for this parameter configurations, it still the case that $W(\alpha_1^D, \alpha_2^D) < W(\alpha^C)$.

Third, I consider the effect of pollution benefit parameter μ . By simplifying the expression $\frac{W(\alpha_1^D, \alpha_2^D)}{W(\alpha^C)}$, it turns out that the centralized enforcement is preferred.

Finally, allow only θ vary in the dimension that it only differs across regions, $\theta_1 \neq \theta_2$,

$\theta_i^C = \theta_i^D$, $i = 1, 2$. The ratio of total welfare can be written as follows:

$$\frac{W(\alpha_1^D, \alpha_2^D)}{W(\alpha^C)} = \frac{4 \left(1 + \frac{\theta_1^2}{\theta_2^2}\right)^{2/3}}{3 \left(1 + \frac{\theta_1}{\theta_2}\right)^{4/3}}$$

For this expression to be larger than 1, $\frac{\theta_i}{\theta_j} > 3.4$, for $i, j = 1, 2$, $i \neq j$ needs to be satisfied. ■

3.7.3 Proof of Proposition 3.8

Proof. The regional welfare under decentralized structure $W_i(\alpha_i^D)$ is known from Lemma 3.4, so information of local welfare welfare under centralized enforcement is needed, that is,

$$W_i(\alpha^C) = \pi_i(\alpha^C) - \lambda_i(e_1(\alpha^C) + e_2(\alpha^C))^2 \text{ for } i = 1, 2$$

Substitute the optimal inspection probability α^C from Lemma 3.3 (note here $\lambda^C = \lambda_1 + \lambda_2$) into this expression, we arrive to

$$W_i(\alpha^C) = \left[\frac{\frac{\mu_i^2}{\theta_i^C} + \frac{\mu_j^2}{\theta_j^C}}{(\lambda_1 + \lambda_2) \left(\frac{\mu_i^2}{(\theta_i^C)^2} + \frac{\mu_j^2}{(\theta_j^C)^2} \right)^2} \right]^{1/3} \left(\frac{\mu_i^2}{4\theta_i^C} - \frac{\lambda_i \left(\frac{\mu_i^2}{\theta_i^C} + \frac{\mu_j^2}{\theta_j^C} \right)}{16(\lambda_1 + \lambda_2)} \right), \text{ for } i, j = 1, 2, \quad i \neq j$$

Together with $W_i(\alpha_i^D)$, I continue with the comparison.

Start with $\lambda_1 \neq \lambda_2$, and $\mu_1 = \mu_2$, $\theta_i^k = \theta_j^m$, where $i, j = 1, 2$ and $k, m = C, D$. The ratio of regional welfare becomes:

$$\frac{W_i(\alpha_i^D)}{W_i(\alpha^C)} = \frac{\left(3 - \frac{\lambda_i^2}{\lambda_j^2}\right) \left(1 + \frac{\lambda_i}{\lambda_j}\right)^{4/3}}{2^{2/3} \left(2 + \frac{\lambda_i}{\lambda_j}\right) \left[\frac{\lambda_i}{\lambda_j} \left(1 + \frac{\lambda_i^2}{\lambda_j^2}\right)\right]^{1/3}}$$

$\frac{W_i(\alpha_i^D)}{W_i(\alpha^C)} > 1$ holds only if the ratio $\frac{\lambda_i}{\lambda_j}$ satisfies $\frac{\lambda_i}{\lambda_j} > 1.18$.

By applying the same method when only μ is different across regions, we get to the similar condition, $\frac{W_i(\alpha_i^D)}{W_i(\alpha^C)} > 1 \Leftrightarrow \frac{\mu_i}{\mu_j} > 2.04$.

For differing in θ with $\theta_i^C = \theta_i^D$, $i = 1, 2$ and $\theta_1 \neq \theta_2$. Similarly,

$$\frac{W_i(\alpha_i^D)}{W_i(\alpha^C)} = \frac{\left(1 + \frac{\theta_i^2}{\theta_j^2}\right)^{2/3}}{\left(1 + \frac{\theta_i}{\theta_j}\right)^{1/3} \left(\frac{9}{4} + \frac{\theta_i}{4\theta_j}\right)} > 1 \Leftrightarrow \frac{\theta_i}{\theta_j} > 3.1$$

■

3.7.4 Proof of Proposition 3.9

Proof. For the condition $\frac{W(\alpha_1^D, \alpha_2^D)}{W(\alpha^C)} > 1$ to be satisfied, the following inequality should hold.

$$\frac{W(\alpha_1^D, \alpha_2^D)}{W(\alpha^C)} > 1 \Leftrightarrow \left(\frac{8 - 2\left(\frac{\lambda_0}{\lambda^C}\right)^{-1}}{3\left(\frac{2\lambda_0}{\lambda^C}\right)^{1/3}}\right)^{2/3} > 1 + \frac{2\frac{\theta_1}{\theta_2}}{1 + \left(\frac{\theta_1}{\theta_2}\right)^2} \quad (3.2)$$

The left-hand side of the inequality is a \cap -shape function, and achieves its maximum of 1.36 at $\frac{\lambda_0}{\lambda^C} = 1$. For the right-hand side, it gets the maximum value of 2 when $\frac{\theta_1}{\theta_2} = 1$. Hence, for this inequality to hold, one important condition is that the value of $\frac{\theta_i}{\theta_j}$ is away from 1, suggesting a large heterogeneity in inspection effectiveness θ . To further support this inequality, it is better that $\frac{\lambda_0}{\lambda^C}$ goes close to 1. Besides, $\frac{\lambda_0}{\lambda^C} > 0.38$ is required to ensure the left-hand side bigger than 1, meaning a high level of local concern on the environment. ■

3.7.5 Proof of Proposition 3.10

Proof. Given $\lambda_1 = \lambda_2 = \lambda_0$, $\mu_1 = \mu_2$, $\theta_1 \neq \theta_2$, canceling the common terms for the welfare of both centralized and decentralized enforcement, it gives:

$$\sum_{i=1}^2 W_i(\alpha^C) < \sum_{i=1}^2 W_i(\alpha_i^D) \Leftrightarrow \left(\frac{2^{1/3}}{\left(\frac{\lambda_0}{\lambda^C}\right)^{1/3} \left(2 - \frac{\lambda_0}{\lambda^C}\right)}\right)^{2/3} > 1 + \frac{2\frac{\theta_1}{\theta_2}}{1 + \left(\frac{\theta_1}{\theta_2}\right)^2} \quad (3.3)$$

The right-hand side is similar as what is obtained in the comparison of central perspective in proposition 3.9. The left-hand side is different, since this expression is a \cup -shape curve and is always bigger than 1. Then for this inequality to hold, a looser

solution is needed comparing to the case from central authority's perspective, that is, (a) $\frac{\lambda_0}{\lambda^C}$ is away from the $\frac{1}{2}$, which corresponds to $\lambda^C = \lambda_1 + \lambda_2$ and $\lambda_1 = \lambda_2$, suggesting that $\frac{\lambda_0}{\lambda^C}$ either low or high, that is, the local government either cares too much or too little about the environment; and (b) $\frac{\theta_i}{\theta_j}$ is away from 1 as before, i.e, there is a large heterogeneity in monitoring effectiveness across regions. Notice that if $\frac{\lambda_0}{\lambda^C}$ or $\frac{\theta_i}{\theta_j}$ is in very extreme cases (for example when it goes to zero or small enough), then this inequality always hold. ■

3.7.6 Proof of Lemma 3.12

Proof. Maximize $W_1(\alpha^{SD})$ with respect to α_1^{SD} yields the first order condition as:

$$-\frac{\mu_1^2}{4(\alpha^{SD})^2\theta_1(t+r)} + \frac{\lambda_1}{[2(t+r)]^4} \left(\frac{\mu_1^2}{(\alpha^{SD})^2\theta_1^2} + \frac{\mu_2^2}{(\alpha^{SC})^2\theta_2^2} \right) \frac{4\mu_1^2}{\theta_1^2(\alpha^{SD})^3} = 0$$

Similarly, the first order condition of the maximization problem of region 2 is:

$$-\frac{\mu_2^2}{4(\alpha^{SC})^2\theta_2(t+r)} + \frac{\lambda_2 + \gamma\lambda_1}{[2(t+r)]^4} \left(\frac{\mu_1^2}{(\alpha^{SD})^2\theta_1^2} + \frac{\mu_2^2}{(\alpha^{SC})^2\theta_2^2} \right) \frac{4\mu_2^2}{\theta_2^2(\alpha^{SC})^3} = 0$$

Combining these two conditions, it yield the relationship between two structures:

$$\alpha^{SC} = \frac{(\lambda_2 + \gamma\lambda_1)\theta_1\alpha^{SD}}{\lambda_1\theta_2}$$

Substitute this back, the optimal inspection of both α^{SC} and α^{SD} can be obtained as written in the Lemma. ■

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Chapter 4

Inside-firm Incentive and Corporate Environmental Performance

4.1 Introduction

Enacting environmental protection legislation has become a commonplace activity of governments all around the globe during the last decades. While the legislation is usually full of good intentions, and despite the evident need of preserving the environment, getting corporations to comply with it has become a serious challenge for administrations at the local, regional, national and international levels. As a matter of fact, environmental violations are documented as the most frequent form of corporate illegality (Hill et al. 1992). In a more detailed report by Clinard (1979), among 6 categories of illegal corporate behaviors¹, environmental violation accounts for a substantial portion of 30%, ranking in the first position together with manufacturing violations. From the perspective of the regulator, the compliance performance has not been satisfactory either. Regarding the compliance statistics of Clean Air Act² in the United States, the

¹6 categories: environmental, manufacturing, labor, financial, administrative and other violations.

²A United States federal law aiming in controlling air pollution in a national level. It is developed and enforced by the Environmental Protection Agency.

average violation rate for all sources is 7% in the fiscal year 2009, and a dramatically higher ratio 24% for only major facilities. Among these 9735 facilities which are caught in violation, 30% of them do not fulfill the requirements to correct their environmental deviations and end up with a total penalty of 144,607,965 dollars.

One would ask, what influences a firm's environmental compliance behavior? The elements that may play a role can be divided into two categories. The first one concerns the external factors, i.e., the environmental policy, inspection, and enforcement mechanisms such as penalties and sanctions. The second one is the internal factors, such as corporate culture, financial status, management incentives, among others, which are elements from the inside-firm viewpoint.

The first category has been explored extensively in the environmental enforcement literature. An intuitive conclusion from this stream of literature is that a more stringent environmental policy, either in the dimensions of emission standards, monitoring, or penalties, restrains the environmental violation probability. But this deterrent effect is applied to all firms under regulation, and the theory has only been able to explain their general response to the external factors. It could be the case that the company who performs better in corporate environmental behavior also behaves better than other companies under a distinctive environmental policy. Hence, it can not capture the heterogeneity of in-compliant behaviors across firms. For this reason, I expect to shed some light on how the internal factors can better explain different corporate environmental performances.

Within the scope of internal firm characteristics, corporate governance is one of the most important elements. Miles (1987) suggests that the philosophy of the top management team is a critical factor in the degree to which a firm exhibits social responsiveness. However, most of the environmental enforcement research has considered the firm as a black box, where decisions are made and carried out consistently from top to bottom in the organization. Little attention has been paid to the organizational obstacles that influence the firm's environmental resource allocations. In practice, where the ownership and control rights of a firm are separated, the principal-agent problem arises. Given

different objectives of the shareholder and the manager, there is good reason to believe that the manager does not always act to the best interests of the shareholder. For instance, a manager may decide to illegally dispose some hazardous waste, disregarding of the long-term goal of the shareholder, to increase his bonus which depends on the profitability. The extent of the conflict between the shareholder and manager's interests determines the degree of corporate non-compliance with environmental law. The corporate control performance is thereby key to the heterogeneity of corporate environmental performances observed. Hence in this paper, I analyze whether and how the firm's corporate governance affects its environmental performance, using both theoretical and empirical methods.

In the analysis, I first develop a theoretic model for a representative polluting firm. The managers control the firm by putting efforts in two tasks (Gabel and Sinclair-Desgagne, 1993): production in pursuit of profit, and pollution abatement for environmental compliance. Unlike previous literature which models these two tasks as independent, I consider a more realistic situation where they are correlated, with the marginal abatement cost decreases with the production level because of economies of scale. The wage scheme and the environmental policy are exogenously given. The firm is subject to environmental regulation, where a penalty is imposed if an excessive emission than the environmental standard is audited and identified. The manager's utility function consists of three parts, the incentive pay from the profit, the personal loss due to environmental violation, and his effort disutilities. Except the heterogeneity of firm characteristics in cost efficiency and bonus pay, the main element of my concern on corporate control level lies in the effort disutility, with a poorer corporate governance associated to less incentives for the manager to work.

I show that the equilibrium efforts of both production and pollution abatement by the manager increase when the corporate governance is better. The resulting environmental violation represents an inverse-U shape with respect to the corporate governance level, where improved corporate governance first aggravate and then lessen the environmental illegality. This is due to the correlated effect between production and pollution

reduction, where abatement technology becomes more efficient as the production increases (Gersbach and Requate, 2004). An improvement in corporate control motivates the manager to devote more to production expansion when the corporate governance is poor. If otherwise, it provides more incentives for the manager to abate pollution, because of economies of scale in abatement technology. In other words, good corporate firms put more effort in pollution reduction, while the managers of poor corporate governance firms produce and pollute much less. Hence, firms in both extremes of corporate control level show a relatively better environmental performance. Additional to the conventional expectation that an improvement of a firm's corporate governance should reduce its environmental non-compliance, I show that the reverse effect can also take place, thereby a firm may face a dilemma between enhanced corporate governance and worsening environmental compliance.

If the firm is in a highly profitable sector, the abatement technology is sufficiently efficient, or the environmental regulation is lax, the relationship can be restricted to only the decreasing part, with environmental violation decreases with the corporate governance level. It can demonstrate a reverse relation if the parameters move to the other extreme. The policy implication is that, knowing the firms' compliance pattern in different sectors, the budget constrained inspection agency could better target the violating firms with respect to their corporate control level.

Following the model, an empirical analysis is conducted using a combined dataset merging from annual report, Bebchuk et al. (2009) and U.S. Environmental Protection Agency Air Facility System compliance dataset. A panel data sample of 83 public-traded firms from three polluting sectors is built for the time period 1998 to 2008. Basing the empirical model on the theoretic predictions, I find that there exists an inverse-U shaped relation between the firm's environmental non-compliance and its corporate governance. The estimation result remains robust after controlling for heteroskedasticity and endogeneity problem. Furthermore, the deterrent effect of routine inspection is also confirmed.

Contrary to the heated concern on the internal factor of a firm and its effect on

corporate environmental compliance in practice³, few studies exist in the academic research. Theoretically, Gabel and Sinclair-Desgagne (1993), Goldsmith and Basak (2001), Franckx and de Vries (2004) study the optimal incentive contract between the shareholder and manager for pursuing both profitable and environmental goals, with different focus on manager's effort, environmental performance indicators and environmental liability rules. In this paper, I do not concern the contractual issue within the firm, but rather assumes that the contract is existed and exogenous and concentrates upon its effect on the corporate environmental performance. Moreover, this paper introduces a more practical model with productive and environmental tasks correlated, which is also the essential difference between the environmental violation and other corporate illegalities.

For the empirical research, it relates more to the corporate social responsibility in the business literature. Earnhart and Lizal (2002), Kassinis and Vafeas (2002), Klassen and Whybark (1999) and Dasgupta et al. (2000) investigate relationships between ownership and emission, board size and lawsuit, manager and environmental investment pattern, management and environmental compliance, respectively. They all result in a positive correlation, where a better management or board structure is associated with better environmental performance. On the contrary, negative relationship is also found between inside control (or corporate governance) and the decision to join the voluntary environmental program in DeCanio and Watkins (1998), as well as in Fisher-Vanden and Thorburn (2011). In my paper, the empirical analysis may be most correlated with McKendall et.al (1999) where they fail to discover a significant linear relationship between board structure and environmental violation. Besides, the research by Halme and Huse (1997) and McGuire et. al (2003) do not end up with any significant relation either. This paper is different by including in the empirical model a second order approximation for corporate governance level, which is derived from the theoretic results.

³Firms launch their own environmental management system, involve in voluntary environmental program; managers have environmental obligations included in the contracts, and there are currently over 300 consulting firms worldwide providing services related to environmental management.

The significant inverse-U relationship I find implies that this model better captures the relation between firm's corporate structure and its environmental performance. Ignoring the second order effect and estimating the model with only linear structure in previous empirical research cannot account for the offsetting effects of increasing and decreasing trends, resulting in the true effect being hidden and no significant relationship being identified.

The paper is organized as follows. In Section 4.2, I describe the theoretic model. Section 4.3 presents the equilibrium and the effect of corporate governance on the environmental violations. The prediction from the theoretic model is tested and analyzed in Section 4.4. The last section concludes.

4.2 The Theoretic Model

Consider a representative firm where its ownership and control rights are separated. The firm's production activity has an adverse effect on the environment. The manager, who runs the business of the firm, makes decisions on both production and environmental activities. In line with Gabel and Sinclair-Desgagne (1993), the manager allocates his effort or time on two tasks: the production effort e and the effort a to abate pollution associated to the production process.

The manager's production effort e translates to the same amount of product. The output of the firm allows to obtain a revenue μe for the firm. The parameter μ combines the price of the product which is exogenously set, and the productivity of the production technology or that of the manager's production effort e . The firm's production cost is increasing and convex in the manager's production effort, or say, the output level e , and takes the form: e^2 .

The pollution is emitted during the production process as a by-product. To comply with the environmental regulation, the firm can reduce its production level, or it can adopt some measures to reduce the pollution emitted. The emission level associated to a production effort e and an abatement effort a is $x = e - a$. The pollution abatement

technology is costly, and the cost function takes the form $\frac{\delta a^2}{e}$. This implies that the abatement cost is convex in the pollution reduction effort a , where more abatement makes the pollution reduction more costly. Besides, the cost associated with the pollution abatement also depends on the production level e . I consider that the abatement technology has diminishing marginal productivity, and the marginal abatement cost is decreasing with the production level (Gersbach and Requate, 2004). In other words, when the output is higher, abating each unit of pollution is more efficient. The abatement cost parameter δ represents the abatement possibilities in different industries. It can also be interpreted as a financial indicator, measuring to what extent the financial situation of the firm allows it to adopt this abatement technology.

The polluting firm is subject to an environmental regulation that establishes an emission standard \bar{s} . To induce compliance, the environmental policy is coupled with an auditing strategy aimed to identify incompliant firms. With a certain probability, the firm is inspected and its volume of pollution is correctly revealed. If the detected emission $(e-a)$ exceeds the permitted standard \bar{s} , the firm triggers an in-violation status. For a violator with $V = e - a - \bar{s} > 0$, a penalty has to be paid to the environmental authority with the sanction function $\alpha(e - a - \bar{s})$. Otherwise, if $e - a - \bar{s} \leq 0$, that the firm over-complies with the environmental regulation, it would not be rewarded and hence the environmental fine is 0.

The firm's profit is written as:

$$\pi = \mu e - e^2 - \frac{\delta a^2}{e} - \alpha(e - a - \bar{s})$$

where $\alpha(e - a - \bar{s}) > 0$ for all (e, a) s.t. $e - a - \bar{s} > 0$ and $\alpha(e - a - \bar{s}) = 0$ for all (e, a) s.t. $e - a - \bar{s} \leq 0$.

For the manager's compensation, he receives a share θ ($\theta \in (0, 1)$) of the firm's profit for incentive pay and a base salary F . Besides, there may occur a cost for the manager associated with environmental illegality, in terms of extra penalty imposed on him or a reputation loss. I denote this by $\beta(e - a - \bar{s})$ with $\beta(e - a - \bar{s}) > 0$ for all (e, a) s.t. $e - a - \bar{s} > 0$ and $\beta(e - a - \bar{s}) = 0$ for all (e, a) st. $e - a - \bar{s} \leq 0$.

Finally, exerting efforts in either production or pollution abatement brings a disutility to the manager, denoted as $g(e + a)$, $g > 0$, which also measures the incentive term that shareholders impose on the manager. The parameter g represents the corporate governance level, with a smaller value of g associated with a better corporate control level⁴. A smaller g makes the term $g(e + a)$ smaller, which reflects the common fact that a better corporate governance (smaller g) makes the managers less costly to work, or say, provides more incentives for them to work. Regardless of any specific mechanism in corporate control such as external audit, threat of dismissal, or promotion incentives, a good corporate governance in my model serves for motivating the manager to work no matter in which task, instead of pursuing his private benefit that does not bring any revenue to the firm. When the corporate control is bad, the alternative choice of personal benefit becomes more attractive and more easily accessible. It makes the manager in a bad corporate governance firm more prone to shirk, and shift his work hours to leisure or private benefit. This corresponds with less incentives in working, or $g(e + a)$ more costly, thereby resulting in a higher level of g . Consequently, as g decreases, the company motivates the manager better towards the shareholders' interests, in accordance with a better corporate control.

Consequently, the manager's utility function is composed of three components: wage benefit, personal loss on environmental illegality, and effort disutility.

$$W = F + \theta \left(\mu e - e^2 - \frac{\delta a^2}{e} - \alpha(e - a - \bar{s}) \right) - \beta(e - a - \bar{s}) - g(e + a)$$

Defining $\alpha\theta + \beta = \lambda$, it can be rewritten as the following:

$$W = F + \theta \left(\mu e - e^2 - \frac{\delta a^2}{e} \right) - \lambda(e - a - \bar{s}) - g(e + a) \quad (4.1)$$

with $\lambda(e - a - \bar{s}) > 0$ for all (e, a) s.t. $e - a - \bar{s} > 0$ and $\lambda(e - a - \bar{s}) = 0$ for all (e, a) st. $e - a - \bar{s} \leq 0$.

⁴In empirical analysis in the following section, the corporate governance index is similar, with a smaller measure representing a better corporate governance.

There is no information asymmetry. Given all other parameters, the manager who is in control of the company chooses the allocation of efforts on tasks of profit-enhancing e and environmental compliance a . Once production and emissions are realized, the environmental agency audits the firms according with his inspection strategy. If the firm is found to be in compliance, nothing happens. On the contrary, if the firm is caught for pollution violation, the agency applies a penalty to the firm.

4.3 The Equilibrium and Analysis

4.3.1 The allocation of manager's effort

The wage scheme (F, θ) and environmental policy instruments are predetermined. Given these parameters and firm's organizational characteristics of corporate governance g , the personal loss parameter λ , production and the abatement productivity parameter μ and δ , a manager chooses the effort on production and pollution abatement to maximize his utility. Assuming interior solution, the first order conditions are the following:

$$\frac{\partial W}{\partial e} = \theta \left(\mu - 2e + \frac{\delta a^2}{e^2} \right) - \lambda - g = 0 \quad (4.2)$$

$$\frac{\partial W}{\partial a} = -\frac{2\theta\delta a}{e} + \lambda - g = 0 \quad (4.3)$$

For $a = 0$, it can be obtain from (4.2) that $e = \frac{1}{2}(\mu - \frac{\lambda+g}{\theta})$. In the following, I focus on the case $V > 0$ which is $\frac{1}{2}(\mu - \frac{\lambda+g}{\theta}) > \bar{s}$, meaning that the non-adoption of any abatement effort or control on the pollution induces a violation of the environmental standard.

The case where $\frac{1}{2}(\mu - \frac{\lambda+g}{\theta}) \leq \bar{s}$ is not interesting. Note that for a given \bar{s} , it corresponds to the situations that the revenue associated to the manager's production effort μ is small, the incentive pay θ is low, the corporate governance is poor, or the environmental policy (including the auditing probability, inspection efficiency, marginal penalty and personal loss parameter) is too stringent. Such over-compliance behavior ($V \leq 0$) in environmental regulation is due to under-production, where the production level is

so low that the emission without any abatement is still lower than the environmental standard. Firms whose production (also pollution) is high never over-comply, because a profit maximizing firm would not spend any extra resource on pollution reduction when it is already in compliance. In the over-compliance case where the environmental violation is always zero, it does not provide useful implications for environmental enforcement, neither would it be the focus of this paper. Thus, I concentrate on the case $V > 0$ for the rest of the analysis, which can be rewritten as $g < \theta\mu - \lambda - 2\theta\bar{s}$.

I consider another condition⁵ that restricts the firms to only environmentally violating ones, that is, $\mu < 2\delta$. This assumption rules out firms with very efficient abatement technology (δ small) relative to their production process, in which case the firm tend to always comply with the environmental regulation.

The following proposition presents the full solution of the optimal effort allocation.

Proposition 4.1 *Given the wage scheme F , θ , the environmental policy \bar{s} , α , β , and the firm characteristics g , λ , μ , δ , the equilibrium levels of both production and environmental effort of a manager (e , a) are given as:*

(1) *If $g \in (0, \lambda)$, then the optimal e and a are:*

$$e = \frac{1}{2} \left[\mu + \delta \left(\frac{\lambda - g}{2\theta\delta} \right)^2 - \frac{\lambda + g}{\theta} \right]$$

$$a = \frac{\lambda - g}{4\theta\delta} \left[\mu + \delta \left(\frac{\lambda - g}{2\theta\delta} \right)^2 - \frac{\lambda + g}{\theta} \right]$$

(2) *If $g \in [\lambda, \theta\mu - \lambda - 2\theta\bar{s})$, then $e = \frac{1}{2}(\mu - \frac{\lambda+g}{\theta})$ and $a = 0$.*

Both the equilibrium of production and abatement effort exerted by a manager are non-decreasing in the firm's corporate governance level.

The corner solution where $g \in [\lambda, \theta\mu - \lambda - 2\theta\bar{s})$ corresponds with the case that the corporate control is very poor. As a result, it induces the firm unwilling to abate

⁵This assumption does not change the main result of the paper, only makes the calculation more straightforward.

any pollution, i.e. $a = 0$, despite that it suppresses the firm's incentive in production too. The firm's compliance behavior only depends on his initial pollution, i.e. the production e . It is decreasing as the corporate governance gets worse until the firm only produces, or pollutes as the regulator allows, \bar{s} . Such situation may exist, but it is not common phenomenon. In the following, I focus the analysis on the interior solution of the optimal allocation on efforts where $g < \lambda$. Since the environmental standard satisfies $\bar{s} < \frac{1}{2}(\mu - \frac{\lambda+g}{\theta})$, it is sufficient to assume that $\bar{s} < \frac{\mu}{2} - \frac{\lambda}{\theta}$, which holds for all corporate governance level in this area.

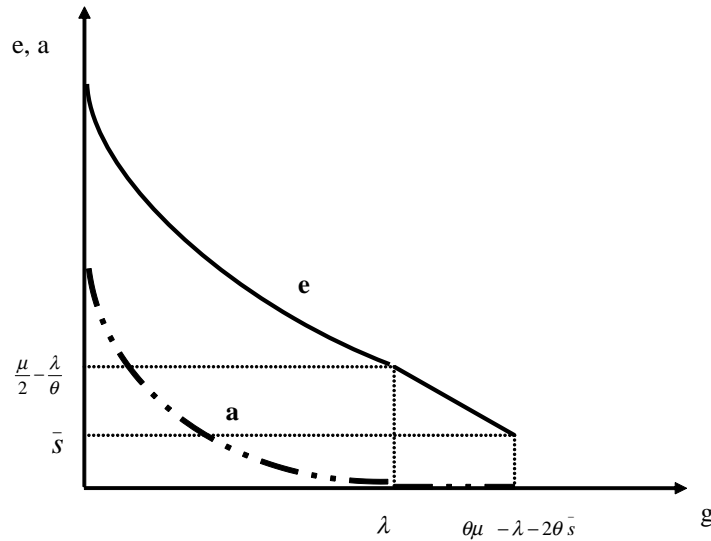


Figure 1: The optimal allocation of efforts on production and pollution reduction

If studying the comparative static of the manager's decision as a function of the corporate governance, I obtain $\frac{\partial e}{\partial g} < 0$, and $\frac{\partial a}{\partial g} < 0$. Since a smaller g measures a better corporate governance level, it suggests that both the effort on production and abatement are increasing with better corporate governance. The manager in a good corporate governance firm tends to work more, not only on production, but also on environmental compliance activities. On the contrary, the worse the corporate governance is, more time the manager spends on his own private benefit enjoyment, resulting in less efforts on production and pollution reduction.

The manager's base salary F does not play a role on the manager's allocation of time. However, the manager's compensation scheme does matter because a higher incentive compensation θ motivates the manager to pursue more production revenue and the pollution reduction since $\frac{\partial e}{\partial \theta} > 0$ and $\frac{\partial a}{\partial \theta} > 0$. As for the technology for production and pollution reduction represented by the parameters μ and δ respectively, their influence on the equilibrium outcome goes in accordance with intuition: both the production and abatement efforts are increasing in the technology efficiency, or say, decreasing in the cost parameter; that is, $\frac{\partial e}{\partial \mu} > 0$, $\frac{\partial a}{\partial \mu} > 0$ and $\frac{\partial e}{\partial \delta} < 0$, $\frac{\partial a}{\partial \delta} < 0$. For parameter λ which also implies the environmental regulation, the more stringent the enforcement policy becomes, the lower effort would be put on the revenue generation, while more emphasis is put on the pollution reduction.

4.3.2 Effect of corporate governance on the firm's environmental compliance

Given the optimal decisions described in section 4.3.1, the initial emission level $x = e$ and the pollution abatement a are also obtained. Therefore, I can analyze whether and how the corporate governance influences firm's environmental noncompliance. The environmental violation can be written as a function of model parameters as the following:

$$V = \frac{1}{2} \left(1 - \frac{\lambda - g}{2\theta\delta} \right) \left[\mu + \frac{(\lambda - g)^2}{4\theta^2\delta} - \frac{\lambda + g}{\theta} \right] - \bar{s} \quad (4.4)$$

Studying the derivative of V with respect to g , the relationship between firm's corporate governance and environmental noncompliance can be captured.

$$\frac{\partial V}{\partial g} = \frac{1}{4\theta\delta} \left(\frac{3(\lambda - g)^2}{4\theta^2\delta} - \frac{\lambda + g}{\theta} + \mu - 2\delta \right) \quad (4.5)$$

$$\frac{\partial^2 V}{\partial g^2} = \frac{1}{4\theta\delta} \left(-\frac{3(\lambda - g)}{2\theta^2\delta} - \frac{1}{\theta} \right) < 0 \quad (4.6)$$

Note that the second order condition is always negative since $\lambda > g$, representing a diminishing second-order effect of g on V . The first order condition $\frac{\partial V}{\partial g}$ can be positive

and is always decreasing with g . Therefore, I present the following Proposition with which the prediction will be brought to the data in the next section.

Proposition 4.2 *A firm's environmental violation exhibits an inverse-U trend with respect to its corporate control level, with a second-order effect strictly negative. Depending on the parameters, the trend may be restricted to only the increasing part $\frac{\partial V}{\partial g} > 0$ if the revenue parameter (μ) is large, the manager's bonus rate (θ) is high, the environmental enforcement is lax (λ small) or the abatement technology is very cost-efficient (δ small); otherwise only the decreasing part remains if the parameters go to the other extreme.*

The environmental noncompliance first increases with the corporate governance, and then decreases. For the increasing part, it happens when corporate governance control is bad, as a result the production level is low. Improving the corporate governance induce the manager to enlarge the production capacity. The pollution abatement also increases, but since the production level is not so high, the abatement technology can not be very efficient due to the correlation between production and pollution reduction. The marginal abatement cost is relatively more expensive than the marginal cost in production expansion, hence the production increases more than the abatement as corporate governance improves, resulting in more severe environmental violation. For the decreasing trend, when the production level is high enough, the abatement technology has economies of scale. The pollution reduction becomes efficient, making the abatement level increases more rapidly than the production does, which leads to a better environmental compliance.

Hence, more compliance can be expected from either well-behaved or poor corporate governance firms, leaving the firms with an average corporate governance violating more the environmental law. The interpretation is that, for the managers in good corporate governance firms, they are better monitored to work for the shareholders' benefit, thereby put more effort on pollution reductions. While on the other extreme of firms with very bad corporate governance, though less pollution is abated for the absolute amount, less emission was produced at the same time, which exhibits a relatively good

performance of environmental compliance. As for the managers in a firm of an average corporate governance, they do not exert much effort in environmental protection, but still, they pursue the profit goal as much as they could, which leads to a much higher end-of-pipe emission.

If μ is big enough, representing a very efficient production process, or a high revenue sector (price is high), it leads to the case that the effect of corporate governance on the environmental violation is monotone, where improved corporate governance reduces the environmental noncompliance volume. This situation can also arise when either the abatement technology is cost efficient (δ small), or the wage compensation rate is generous (θ large). In a word, in sectors with cost-efficient technologies, the corporate environmental illegality is decreasing with its corporate governance level. This can be expected from the conflict of interests between the shareholder and managers. On one side, the managers are short-sighted caring about their wage benefit, thereby pay more attention to the short-term profit. On the other side, the shareholders are more concerned on the long-run profit and the firm's reputation, which includes the compliance to the environmental law. Hence, in a good corporate governance firm, the managers are better controlled to perform toward the shareholders' interests. Besides pursuing the profit goals, the managers take more effort on the environmental compliance activities, which results in less violations.

If all these parameters go to the other extreme, with very inefficient technology in abatement process or the marginal revenue is low enough, the environmental noncompliance becomes more severe when the corporate governance gets better. The result appears a bit surprising, but under the circumstances that the abatement technology is so expensive that it is seldom utilized, the firm with a good corporate governance who produces more ends up with more violation.

Therefore, if a firm experienced a change in corporate structure which leads to a better corporate governance, one would expect that its environmental compliance will become better if the firm is in a cost-efficient sector. However, it can also be the case that improved corporate governance leads to a higher environmental noncompliance. If a

firm's abatement technology is inefficient, enhanced corporate governance level provides a higher incentive for the manager to devote to production activities than pollution reduction, resulting in more environmental violation amount. More possibly, a change in firm's corporate control brings uncertain effects on its environmental performance, depending on the corporate governance is locating on which part of the inverse-U shape. Additional to the conventional expectation that an improvement of a firm's corporate governance should lessen its environmental noncompliance, I show that the reverse effect can also take place. Hence, any policy that aims to improve on the firm's environmental performance by means or incentives of increasing its corporate governance level, should be given a second thought.

Knowing the firms' noncompliance patterns with respect to different characteristics of sectors, the environmental inspection authority could respond accordingly. It is a prevalent fact that the agencies have a limited budget in their monitoring activities. Therefore, how to allocate their monetary and human resources to restrain more environmental noncompliance behaviors is worth discussing. In general, the regulatory authority conducts occasional inspections in response to civil complaints, historical violation, excessive smoke or dust. Based on the analysis, it could be recommendable to target the most potential violative firms by their internal properties, especially the corporate governance level.

Therefore, to be more efficient in allocating the monitoring resources, the budget-constrained environmental agency should apply different inspection strategies towards different industries. In a cost-efficient or high-revenue sector, more inspections should be imposed on poor corporate governance firms, and the opposite measure should be taken in very inefficient sectors. Other than previous two cases, in average-efficient industries the optimal monitoring should be assigned more frequently to firms with an average corporate governance to better deter the environmental illegality.

With respect to the comparative statistics of other parameters, it could be observed that $\frac{\partial V}{\partial \mu} > 0$. If the firm is in a high revenue sector, or the production procedure is very efficient, managers are motivated to put more effort in the production, and emit more

pollution simultaneously. This logic works the same for the incentive wage parameter in the sense that $\frac{\partial V}{\partial \theta} > 0$. Though a high compensation rate gives an incentive to the managers to work more and make more profit, it also increases the environmental risk of violation.

As for the effect of abatement cost parameter δ on the environmental violation, the relationship is uncertain. In efficient sectors, where $\frac{\partial V}{\partial \delta} > 0$, the abatement cost increases the environmental violation. While in inefficient sectors, the relationship is the opposite, $\frac{\partial V}{\partial \delta} < 0$. In the latter case, the abatement cost is sufficiently high. By lowering the abatement cost in the margin may increase the abatement amount of emission, meanwhile it increases the production more, resulting in a higher environmental noncompliance. For environmental enforcement parameters as α , β or λ , the result is straightforward. The higher the monitoring probability or the environmental fine is, the lower the environmental violation would be. This verifies that the environmental regulation does have a deterrent effect on firms' environmental noncompliance in a general sense.

4.4 Empirical Analysis

4.4.1 Data description

With respect to the effect of corporate governance on the firms' environmental performance, three possible correlations are predicted from the theory. In the following, I test whether or which theoretic prediction applies to the quantitative analysis, using a sample from the United States. The sample consists of domestic Standard&Poor 500 Companies in three sectors: electricity generation, pulp & paper, glass & cement manufacturing, with a total number of 83 firms. According to the U.S. Environmental Protection Agency (EPA)'s National Emissions Inventory (NEI) Air Pollutant Emissions report, these sectors are among the most polluting industries. I then construct a database that includes information on corporate governance, financial status and envi-

ronmental performance for those firms.

Corporate governance and financial variables

In order to have a measure on corporate governance, I use the index constructed by Bebchuk et al. (2009). They report a corporate governance index of all Standard&Poor 500 Companies, with time expanding from 1990 to 2008. The measure is constructed from data followed by Investor Responsibility Research Center (IRRC). It contains provisions as staggered boards, supermajority requirements for mergers, golden parachutes, etc, which matter most in corporate governance. The index results in an integer, from 0 to 6, where the smaller number represents a better corporate governance. The time span is from 1998 to 2008, with a fixed frequency of every two years.

The financial data for each firm was hand-collected from their annual reports. To measure the firm's profitability which may directly influence its incentive or ability to abatement technology purchase, permit trading or pollution reduction efforts, the return on assets (RoA) is used. additionally, the size of the firm can be relevant information which could reflect the firm's perception on reputation building or the implementation of environmental operation within the firm. By tradition, it is measured by the number of employees in that firm.

Environmental variables

The environmental data is obtained from Air Facility System (AFS) of EPA's Integrated Data for Enforcement Analysis (IDEA). The AFS database is tracked for the environmental statute Clean Air Act (CAA), which is an environmental policy uniform across the United States, making the policy variable fixed. The dataset is frequently updated, and contains rich compliance and enforcement information for various air pollutions of 140,000 stationary sources. Among them, 16,000 are major facilities, 26,000 are synthetic minor facilities and federally reportable minor facilities, 98,000 are minor facilities. All facilities are required to self-report their emission to the authorities at

least semiannually. The historical compliance result is available from 1992 up to the present, while the national actions such as inspection or enforcement actions can be traced back to 1978. To be consistent, only data from 1998 to 2008 are drawn. Prior to that, the number of plants who were recorded in the system is significantly less.

The AFS dataset contains some basic information for all facilities. For instance, the name, address, sector, operating status, federally reportable or no. The plants that are not active are dropped, and the rest are matched to the firms of interest. Taking into consideration of the ownership change such as merger or closure, these 83 firms are finally matched with 2518 plants. Among these plants, 61% are federally reportable, or say, they are classified as major or synthetic minor facility. Since federally reportable plants may be subject to a more intense enforcement activities, a firm comprised of more federally reportable plants is likely to have a different attitude toward their corporate environmental practices. Thus, to better distinguish the plant size, I include a variable of the major plants ratio, which is measured by the proportion of federally reportable plants within each firm.

The dataset further specifies each monitoring action, date and type toward a plant. The monitoring can either be a thorough inspection or partial, on-site or off-site, EPA or state conducted, a full compliance evaluation or only toward one targeted air program. Since a firm with more plants may be audited more often than a firm with fewer plants, the variable we consider for the inspection is the average inspection times, which is the aggregated inspection times of the firm in each period divided by the number of plants.

As a result of the monitoring action, the plant is reported to be either in compliance or in violation. A violation may indicate that the facility released excessive pollutants, that a hazardous waste handling requirement was not met, or that a facility failed to submit a required report. The measure for the firms' compliance performance, which is the dependent variable, is measured by the firm's average violation ratio. It is constructed as the aggregate in-violation status times of a firm over all the compliance results times (both in-compliance and in-violation) in each period. The average violation ratio of a firm is a continuous variable between 0 and 1, representing an average environmental

compliance performance across all its plants in each two-year period.

If a facility is caught in violation, the first step of standard procedure is that the EPA or the state issues a warning letter or a notice of violation to the alleged violator. But if the violation is not corrected, the firm will suffer a penalty from either the settlement of a civil administrative action taken by the EPA, or more severely, the fine toward the firm in violation determined by the court. The fine is documented in the dataset, and I add the amount of each plant to the firm level in each period as the penalty variable.

Moreover, the plants of a firm can be operating in one state or several. The more states in which a firm is active, it may lose more control or face more uncertainty because of different enforcement practices of each state. I include the number of states in which a firm has business as a control variable. In addition, since different industries may emit different types of air pollution and have different abatement technologies, the sector dummies are included to be able to control for this dimension.

Descriptive statistics

I end up with an unbalanced panel level sample of 83 firms, corresponding with 2518 plants. Firms have on average 30 plants. The time dimension of the data is from 1998 to 2008, every two years and of six waves. The total number of observations is 410.

Table I: Descriptive Statistics

Variable	Mean	Sd. Dev
Corporate governance	2.93	1.32
RoA	0.03	0.04
Size (thousands of employees)	10.70	12.42
Average inspection times	6.57	0.35
Average violation ratio	0.06	0.11
Penalty (thousands of dollar)	53.48	233.09
State number	6.44	6.98
Major plants ratio	0.71	0.24

Power generation	64%
Paper & pulp	24%
Glass & cement	12%

4.4.2 Empirical model and analysis

The basic model

Using the data described in the previous section, I want to investigate whether and how the inside-firm characteristics, especially the corporate governance dimension, have an effect on its environmental performance. Referring to the theoretical conclusion in Section 4.3, the corporate governance has an indefinite first-order and diminishing second-order effect on the environmental illegality. In order to test this hypothesis, I apply the empirical model as the following:

$$VIO_{it} = \beta_0 + \beta_1 CG_{it} + \beta_2 CG2_{it} + \beta_3 ROA_{it} + \beta_4 SIZE_{it} + \beta_5 INS_{it} + \beta_6 LAGPEN_{i,t-1} + \beta_7 MAJOR_i + \beta_8 STATE_i + \beta_9 SECTOR_i + \beta_{10} YEAR_t + \epsilon_{it}$$

In this equation, the dependent variable VIO_{it} is the corporation's average violation rate in period t . CG_{it} stands for the measure of corporate governance in period t for firm i . Based on the theoretic predictions in the previous section, a quadratic term of corporate governance $CG2_{it}$ is employed to account for the second-order approximation between the corporate governance and the environmental illegality.⁶ ROA_{it} denotes the return to assets calculated by the net income over total assets. It suggests another in-side firm characteristic- the profitability- which may also influence the corporate environmental behavior. $SIZE_{it}$ is used to control the size effect of the firm, measured by number of employees. INS_{it} denotes the average times of firm i being inspected in the period t . $LAGPEN_{i,t-1}$ is the penalty amount that firm i was punished in the

⁶The correlation or causality between two elements is generally complicated and affected by many other factors. A linear relationship can not always be guaranteed. To account for the possible curvature, a quadratic form of the variable is commonly utilized even without a theoretic prediction. In fact, if we run the regression without the quadratic term of corporate governance, the linear relationship between corporate governance and environmental incompliance is always rejected.

previous period $t - 1$. Introducing this term is based on several reasons. First, paying a fine may bring a financial stringency to the firm which influences the incentive to the environmental efforts. Second, being punished may alter the firm's expectations over the monitoring strategy or make it more aware of the public reputation, which changes their next-term behavior. Third, if a firm suffered a major violation in the previous period, such accident or violation may not be corrected immediately. Hence the impact may be carried to the next year, and this can also be measured by the penalty amount. The other four variables $MAJOR_i$, $STATE_i$, $SECTOR_i$, $YEAR_i$, are control variables for the proportion of major plants, state number firm i spreads, sector dummy and year dummy, respectively. ϵ_{it} is the usual error term.

Based on the fact that the sample of all firms is drawn from three specific industries instead of a random subset, and the Hausman test (Hausman test statistics= 29.98) rejects the null hypothesis that the time independent effects for each entity are independent with the regressors, so the fixed effects estimation should be applied.

The empirical results are displayed in Table II. First, it can be observed that both the variables CG and CG2 are statistically significant. One can indicate that the corporate governance structure does exert an effect on the corporate environmental performance. The corporate governance shows a positive first-order effect on the firm's violation behavior. Also, the sign of the quadratic term of corporate governance is negative, as the theory predicts. As for the fitted values, the environmental violation rate is small when corporate governance measure is in the extreme, either very good or bad. And the violation ratio reaches the top when the corporate governance is 3, around the middle. To show it more straightforward, a scatter plot with a fitted line between corporate governance and the environmental noncompliance can be found in Appendix 3. Thus, the empirical result confirms the theoretical prediction in Proposition 4.3. In other words, the corporate governance does not only have a significant impact on the dependent variable. Moreover, their relationship exhibits an inverse-U shape where firms with average corporate governance violate much more the environmental regulation on air pollutions than the firms with either good or bad corporate governance structure.

The penalty amount also demonstrates a strong influence on the dependent variable (significant at 1% level). Together with the positive sign of the estimator, the more penalties induce more environmental non-compliance for the future period. An explanation could be that the fine of environmental violation worsens the firm's financial condition so that the ability to invest in the environmental compliance is cut short; or if the violation is too severe to fix in a short time then the status in violation persists into the next period.

Though the sign of the inspection strategy is negative which conforms to our expectation of its deterrent effect, it does not show any significance for the corporate environmental violation. Additionally, the size of the firm and the corporate profitability are not significant in the regression either. The time-invariant variable of major plants proportion, state number of operation and sector dummies are dropped automatically in fixed effect regressions. Using Hausman-Taylor method to recover these estimates, I found that none of them are significant. Therefore, whether a firm is mainly composed of major or minor plants, in how many states the firm is operating, as well as the industry heterogeneity do not affect firm's environmental performance. These three variables remain insignificant for all later estimations, hence they will not be reported henceforth.

A serial correlation problem can be suspected because of the environmental violation. For instance, the impact of an environmental accident can last for several months. In this quantitative context, the time interval is two years, thus the auto-correlation problem should be minor. Using the test for autocorrelation in panel-data models derived from Wooldridge (2002), it confirms that serial correlation is not a problem that needs worrying. Besides, I try to employ the lagged term of dependent variable, and estimate it with Arellano-Bond dynamic panel data model. It turns out that the lagged effect of environmental violation is insignificant.

Table II: Regression Result- Fixed Effect

Independent Variable	Fixed Effects
CG	0.0305* (0.0167)
CG2	-0.0051** (0.0026)
ROA	0.0853 (0.1667)
SIZE	0.0011 (0.0020)
INS	-0.0009 (0.0014)
LAGPEN	5.72e-08*** (1.98e-08)
YEAR 2000	0.0001 (0.0147)
YEAR 2002	0.0256* (0.0153)
YEAR 2004	0.0210 (0.0160)
YEAR 2006	0.0173 (0.0161)
YEAR 2008	0.0301 (0.0203)
Constant	0.0079 (0.0359)

The standard error is displayed in parentheses.

*, ** and *** denote statistical significance at 10%, 5% and 1% level.

Furthermore, in this panel-level sample with heterogenous firms, the problem of het-

eroscedasticity may arise. Though the heteroscedasticity leaves the estimates unbiased, it causes biased standard errors. To account for the heteroscedasticity across panels, I relax the homoskedasticity assumption by applying the cluster robust on firms with fixed effects estimation. The results can be found in Appendix 4. The corporate governance variable of concern illustrates a strong inverse-U relationship with the environmental illegality. The main finding in the previous fixed effects model still holds.

Endogeneity

Another concern of this empirical study is the possible endogeneity caused by the inspection variable. The endogeneity problem may result from the potential two-way causation of the estimation. Besides the fact that the monitoring practices have an impact on the environmental non-compliance behavior, the inverse causality can also make sense, that is, the violation detected can trigger or influence the monitoring strategy by the environmental agencies.

To cope with this endogeneity, I may look for an instrumental variable for inspection which is closely correlated to inspection but which does not suffer the same endogeneity problem, in other words, the instrument is not correlated with the error term in the explanatory equation. In my dataset, by separating the types of inspection, one category of routine inspection appears to be a good candidate for the instrument. According to the CAA stationary source compliance monitoring strategy report, the inspection process is that the states first submit a plan biennially for discussion with and approval by the regions, and then regions conduct in-depth evaluations of overall state compliance monitoring program periodically. Besides this, the state or local agencies may perform additional compliance monitoring activities. Correspondingly, there are two categories of compliance monitoring as first argued in Liu(1995). One is full compliance evaluation (FCE), also be called routine inspection. It includes comprehensive paperwork review and often, but not necessarily, an on-site inspection. The other is the partial compliance evaluation (PCE), categorized as the discretionary inspection. A full compliance eval-

uation should be conducted at a minimum once every two years except mega-sites and synthetic minor sources. For each facility, the frequency of a full compliance evaluation toward a plant is not endogenously decided by its previous compliance history, community observations or pollution accident, but instead is predetermined by the monitoring routine and hence is exogenous. Moreover, the correlation coefficient between inspection and routine inspection is 0.8282, verifying that the routine inspection can serve as a good instrument.

I apply the fixed effect IV regression, and the results are reported in the Table III. First, comparing this table with estimation results in Table II, the coefficient of each variable is similar. Second, regarding the significant effect, it also remains the same as in the fixed effects estimation, except the corporate governance, inspection variable and the year dummies.

For one thing, both the first and second order approximation of corporate governance demonstrates a slightly stronger significant effect (both significant at 5% level). It suggests that the fit of the inverse-U relation between the corporate governance and environmental noncompliance is better.

For the inspection strategy which was instrumented by the routine inspection, it reveals a significant deterrent effect on the environmental illegality (significant at 5% level). This verifies the deterrent effect of environmental regulation found in the theoretic analysis, where the inspection probability is exogenous and fixed. As also argued in Liu(1995), the routine inspection and discretionary inspection may incur a contrary effect on the firm's environmental violations. On one hand, though the number of routine inspections to be conducted during a certain period is predetermined, exactly when it would be performed is uncertain. As a result, it is expected to decrease both the corporate violation rate and the amount of violated air pollution being detected. On the other hand, the discretionary inspection usually happens when some sign of environmental violation is observed. For example, a rising number of complaints toward a polluting firm, unusual dark smoke and dust in the air, or a bad environmental compliance record of a specific firm, can all trigger the monitoring which is not on the routine

schedule. That is to say, the discretionary inspection serves the function of identifying known or suspicious violations. Thus, such monitoring is associated to a higher volume of violation, or an increased number of noncompliance. When both the two categories of inspections are performed, the combination of the distinct mechanisms thereby results in an indeterminate effect on the illegal environmental behaviors. This explains why in the IV-estimation the routine inspection is significant on the environmental violation deterrence while the inspection is shown of no importance in the fixed effects model.

Table III: Regression with Correction of Endogeneity

Independent Variable	Fixed Effects IV
CG	0.0457** (0.0224)
CG2	-0.0096** (0.0039)
ROA	0.1255 (0.1889)
SIZE	0.0005 (0.0022)
INS	-0.0217** (0.0096)
LAGPEN	4.04e-08 (2.63e-08)
YEAR 2000	-0.0046 (0.0197)
YEAR 2002	0.0689** (0.0294)
YEAR 2004	0.1116*** (0.0419)

YEAR 2006	0.1186***
	(0.0447)
YEAR 2008	0.1581***
	(0.0594)
Constant	-0.0706
	(0.0554)

The standard error is displayed in parentheses.

*, ** and *** denote statistical significance at 10%, 5% and 1% level.

Regarding the effects of year dummies, the first year 1998 was dropped due to collinearity. For the rest of time effects, Year 2002 and afterwards show a strong significance. One explanation is that, in 1999 the EPA Office of the Inspection General conducted interviews with all regions and reviewed the implementation of the monitoring practices, then in 2000 a revised policy on monitoring and enforcement was carried out. The modification in inspection types (especially the routine inspection), monitoring emphasis, self-report frequency and so on may make a significant structural difference for the following years.

Robustness check

Since this paper is aim to analyze the effect of firm's corporate governance on its environmental performance, the quantitative analysis is thereby focusing on the firm level. To check whether the above empirical results are robust, I performed another estimation with data decentralized to the plant level.

The unbalanced panel sample is constructed of 2518 plants, with a quarterly time frequency from 1998 to 2008. The firm's corporate governance and size measure is treated the same across plants. The ROA which measures the profitability of a firm is drawn from the quarterly financial report instead of the annual report. The environmental performance measure is a dummy, with value 1 corresponding to a violation detected in that period. And the monitoring type applied has value 1 when it is a routine inspection,

otherwise it is 0. Moreover, I have information of the penalty amount, sector, whether it is a major plant or not and state dummy for each facility. Since the dependent variable is 0-1 dummies, the logit estimation with fixed effects is employed.

The regression results again reject the linear relationship between the corporate governance and the environmental violations, and support the inverse-U shape theory. The regression results can be found in Appendix 5. The first and second order of corporate governance present a even more significant effect (both significant at 1% level) than results from firm-level estimation. Furthermore, the year dummies and routine inspection yield similar outcome. The only difference of this model is that the firm's profitability measure ROA shows a significant effect in "promoting" environmental illegality. One explanation can be that more resources are allocated to the profit maximization activities thereby the environmental performance is left ignored. To conclude this part, the previous quantitative analysis remain robust for the plant-level data.

4.5 Conclusion

In this paper, I have analyzed whether and how a firm's characteristics, in particular the corporate governance, affect its environmental compliance behavior. My theoretical approach represents, to my knowledge, the first attempt to address the environmental compliance issue from the perspective of the inside-firm characteristics. It does not only confirm the general deterrent effect of environmental enforcement, but also provides an explanation for the heterogeneity of firms' environmental performances. To be more specific, I find that the manager puts more effort or time in working, no matter for production or pollution abatement, when the corporate governance is better. Unless for extreme parameters of technology efficiency, wage scheme, or environmental regulation, the effect of a firm's corporate control on its environmental illegality represents an inverse-U shape. Such trend can be related to environmental Kuznet curve, and Stern (2003) explain some similar logic shared behind. Therefore, an improvement in a firm's corporate governance level can bring about an uncertain impact on its corporate

environmental performances.

The prediction from the theoretic model was brought to an empirical analysis using the dataset constructed from the United States. It confirms that there exists a diminishing-second order effect of the corporate governance on its environmental violation amount, and the severity of environmental illegality demonstrates a trend that it first increases and then falls down with respect to its corporate control level. The quantitative result is robust after I allowed for heteroskedasticity, controlled for endogeneity, and analyzed it also at the plant-level data. This result may serve as an explanation in understanding why in the most related empirical research of McKendall et al. (1999), and Halme and Huse (1997), no significant relationship is found between firm's corporate governance and its environmental illegality. Without a second-order approximation inferred from the theoretic conclusion, modeling it in a linear way can result in true effect being hidden.

The result from the theoretic part is robust to different production or cost function, as long as the general concavity or convexity assumptions are satisfied. Regarding the empirical part, though the database serves the goal in the quantitative analysis, a much richer dataset which includes information on plant age, facility technology employed, or environmental investment can be beneficial in increasing the fit of the model.

4.6 Appendix

4.6.1 Appendix 1: Proof of Proposition 4.1

First, I check the second order conditions.

$$\begin{aligned}\frac{\partial^2 V}{\partial e^2} &= -2\theta - \frac{2\theta\delta a^2}{e^3} < 0 \\ \frac{\partial^2 V}{\partial a^2} &= -\frac{2\theta\delta}{e} < 0\end{aligned}$$

and

$$\frac{\partial^2 V}{\partial e^2} \frac{\partial^2 V}{\partial a^2} - \left(\frac{\partial^2 V}{\partial e \partial a} \right)^2 = \frac{4\theta^2 \delta}{e} > 0$$

Solve for the local maximizer with respect to the objective function (4.1), and subject to the constraint $e - a - \bar{s} > 0$, only two cases are possible, $e > 0$, $a = 0$ and $e > 0$, $a > 0$.

For the first case which is the corner solution, it can happen if $\lambda \leq g$ from (4.3). Since all parameters are positive, and the optimal level of e and a are also non-negative, $\frac{\partial W}{\partial a} < 0$, thereby the optimal effort of pollution reduction a is always 0. Given $a = 0$, the optimal effort of production e can be solved from (4.2), which is equal to $\frac{1}{2}(\mu - \frac{\alpha\gamma\beta+g}{\theta})$.

Since $e - a - \bar{s}$ has to be positive, I concentrate on the case that $g < \theta\mu - \lambda - 2\theta\bar{s}$, otherwise it results in the overcompliance case. Hence, with $\lambda \leq g < \theta\mu - \lambda - 2\theta\bar{s}$ I encounter the corner solution with $a = 0$ and $e = \frac{1}{2}(\mu - \frac{\alpha\gamma\beta+g}{\theta})$.

Assuming interior solutions, that both first order conditions are equal to 0, from (3) I have $\frac{a}{e} = \frac{\lambda-g}{2\theta\delta}$. Substituting this into equation (4.2), one can get

$$\frac{\partial W}{\partial e} = \theta \left(\mu - 2e + \frac{(\lambda - g)^2}{4\theta^2 \delta} \right) - \lambda - g = 0$$

, which yields the optimal effort for production e as:

$$e = \frac{1}{2} \left[\mu + \delta \left(\frac{\lambda - g}{2\theta\delta} \right)^2 - \frac{\lambda + g}{\theta} \right]$$

The optimal effort for pollution reduction a can be solved accordingly with equation (4.3).

$$a = \frac{\lambda - g}{4\theta\delta} \left[\mu + \delta \left(\frac{\lambda - g}{2\theta\delta} \right)^2 - \frac{\lambda + g}{\theta} \right]$$

To ensure $e > 0$ and $a > 0$, g needs to be smaller than λ . e can be further rewritten as the following.

$$e = \frac{1}{8\theta^2\delta} [g - (\lambda + 2\theta\delta)]^2 - \frac{2\lambda}{\theta} - \delta + \mu$$

Note that when $g < \lambda$, the optimal effort in production reaches its minimum when $g = \lambda$. Thereby I only need $e|_{g=\lambda} > 0$, which yields $\mu\theta > 2\lambda$. This condition is automatically satisfied because $\theta\mu - \lambda - g > 2\theta\bar{s} > 0$ holds true for all corporate governance level in the interior solution, hence $\theta\mu - 2\lambda > 0$ when $g = \lambda$.

Note that in this interior solution, the condition $V = e - a - \bar{s} > 0$ is always satisfied. Inferred from the next appendix, the environmental violation amount reaches its minimum at either extreme point of its region $(0, \lambda)$. If $g = \lambda$, the violation amount is equal to $\frac{\mu}{2} - \frac{\lambda}{\theta}$, which is always higher than the emission standard \bar{s} . If $g = 0$, the violation $V = \frac{2\theta\delta - \lambda}{4\theta\delta} (\mu + \frac{\lambda^2}{4\theta^2\delta} - \frac{\lambda}{\theta})$. For this to be larger than \bar{s} , it is sufficient to prove that it is larger than $\frac{\mu}{2} - \frac{\lambda}{\theta}$. For this $3\lambda - \frac{\lambda^2}{2\theta\delta} + 4\theta\delta - 2\theta\mu > 0$ is required. Since $\lambda - \frac{\lambda^2}{2\theta\delta}$ is always positive, I only need that $\lambda + 2\theta\delta > \theta\mu$, which is already satisfied because $\mu < 2\delta$.

Since the corporate governance measure g is non-negative, it results in the interior solution of the optimal allocation (e, a) as defined above when $0 < g < \lambda$.

4.6.2 Appendix 2: Proof of Proposition 4.2

The derivatives of environmental violation V with respect to g have been obtained. Note that the second order condition is always negative since $\lambda \geq g$, representing a diminishing second-order effect of g on V . The sign of the first order condition is uncertain, but the term $\frac{\partial V}{\partial g}$ is always decreasing with g . Considering the critical point for interior solution,

g is bounded between 0 and λ , one can analyze the critical value at the extreme point.

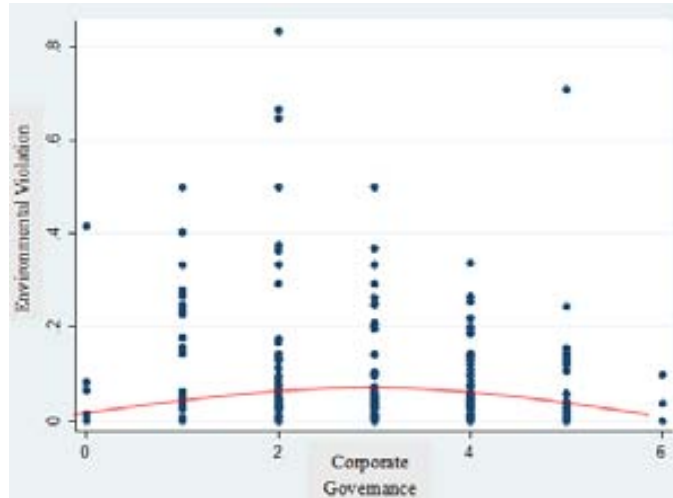
$$\frac{\partial V}{\partial g} \Big|_{g=0} = \frac{1}{4\theta\delta} \left(\frac{3\lambda^2}{4\theta^2\delta} - \frac{\lambda}{\theta} + \mu - 2\delta \right)$$

$$\frac{\partial V}{\partial g} \Big|_{g=\lambda} = \frac{1}{4\theta\delta} \left(-\frac{2\lambda}{\theta} + \mu - 2\delta \right)$$

If $\frac{\partial V}{\partial g} \Big|_{g=0} < 0$, that is, $2\theta\delta + \lambda + 1 - \frac{3}{4}\lambda^2 > \mu\theta$, $\frac{\partial V}{\partial g}$ is always be negative since $\frac{\partial V}{\partial g}$ is decreasing in g . In this case, the environmental violation is increasing (with a diminishing rate) in the corporate governance level, because a higher value of g measures a poor corporate governance level. If $\frac{\partial V}{\partial g} \Big|_{g=\lambda} > 0$, i.e., $\mu\theta > 2\lambda + 2\theta\delta$, it leads to that $\frac{\partial V}{\partial g} > 0$. Hence, if parameters fall into this region, the environmental non-compliance is a decreasing function of the corporate governance. When $2\theta\delta + \lambda + 1 - \frac{3}{4}\lambda^2 < \mu\theta < 2\lambda + 2\theta\delta$, it results in that $\frac{\partial V}{\partial g} \Big|_{g=0} > 0$ and $\frac{\partial V}{\partial g} \Big|_{g=\lambda} < 0$, thus it shows a trend that the environmental violation is first increasing and then decreasing with the firm's corporate governance. Besides, knowing that $\frac{\partial^2 V}{\partial g^2} < 0$, the relationship thereby represents an inverse-U shape.

From these conditions one could infer that as μ or θ gets larger, or λ , δ gets smaller, it moves the effect towards the case that $\frac{\partial V}{\partial g} > 0$.

4.6.3 Appendix 3: Scatter plot with fitted line of corporate governance and environmental violation ratio



4.6.4 Appendix 4

Regression Results: Fixed Effects with Cluster Robust

Independent Variable	Fixed Effects
CG	0.0305*** (0.0108)
CG2	-0.0051*** (0.0014)
ROA	0.0853 (0.0969)
SIZE	0.0011 (0.0014)
INS	-0.0009 (0.0021)
LAGPEN	5.72e-08 (5.90e-08)
YEAR 2000	-0.0001 (0.0087)
YEAR 2002	-0.0256 (0.0242)
YEAR 2004	-0.0210 (0.0207)
YEAR 2006	-0.0173 (0.0189)
YEAR 2008	0.0301 (0.0269)

The standard error is displayed in parentheses.

*, ** and *** denote statistical significance at 10%, 5% and 1% level.

4.6.5 Appendix 5

Robustness Check on Plant Level	
Independent Variable	Fixed Effects
CG	1.4104*** (0.2783)
CG2	-0.2306*** (0.0422)
ROA	3.5768*** (0.8897)
SIZE	0.0931* (0.0491)
INS	-0.3201* (0.1779)
LAGPEN	8.93e-08 (6.62e-08)
YEAR 2000	-2.7664*** (0.4492)
YEAR 2002	-1.1003*** (0.2471)
YEAR 2004	-0.1857 (0.2170)
YEAR 2006	-0.2902 (0.1940)
YEAR 2008	0.1780 (0.2038)

The standard error is displayed in parentheses.

*, ** and *** denote statistical significance at 10%, 5% and 1% level.

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