DEPOCEN

Working Paper Series No. 2012/27

Assessing the impact of formal and informal regulations on environmental and economic performance of Brazilian manufacturing firms*

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*The authors would like to thank the Institute of Applied Economic Research at Rio de Janeiro and the Center for International Development at Harvard University for making the dataset available. Database construction has been funded by the AVINA Foundation. We are also grateful to Marc-Andreas Muendler for providing data on sectoral depreciation rates, to Ronaldo Seroa da Motta for helpful discussions and to Paula Aniceto and Luisa Camaret for providing very efficient research assistance. Lastly, this paper has greatly benefited from long and fruitful discussions with Alban Thomas and Cécile Aubert.

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August 29, 2011

Abstract

This study investigates the impact of formal and informal regulations on environmental and economic performance of Brazilian manufacturing firms. We adopt a dual approach where production technology is represented by a cost function, approximated by a translog form. Pollution is considered as a negative by-product that can be modified trough using either formal regulation (inspections or sanctions) or informal regulation (community pressure). A simultaneous equation model is estimated by three-state least squares on a sample of 404 industrial establishments located in the state of São Paulo, Brazil. We show that pollution abatement costs for the Brazilian manufacturing sector are different from zero which suggests that pollution emissions are affected by environmental regulation. We also demonstrate that environmental performance of firms is jointly affected by formal and informal regulation. Lastly, formal regulation is largely influenced by informal regulation and more specifically by community pressure.

Keywords: Environmental Regulation, Informal Regulation, Firms, Costs, Brazil.

JEL Codes: Q21, Q25, L5.

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1 Introduction

In developing countries, more and more attention is paid to environmental issues arising from population growth and economic development. As a result, a number of developing countries have recently moved from an historical environment regulation system based on a "command and control approach" toward more incentive-based instruments like pollution taxes (emission charge in China and Central Europe), input or output taxes (leaded gas tax in Thailand and Philippines), tradeable permits (water rights in Chile).[1] This trend is not surprising since developing countries have limited financial resources and very often face severe pollution problems, making the command and control approach difficult and costly to implement (especially in the case of a large number of small polluting firms).

However, in developing countries, formal regulation schemes have been greatly hampered by the absence of clear and legally binding rules, by the limited institutional capacity of states and often by inadequate information on emissions, Hartman et al. (1997). The failure of formal regulation to control pollution has highlighted the significance of informal regulation for achieving environmental goals, Kathuria (2007). If anecdotal evidence suggests that informal regulation through local community pressure may force polluters to take corrective action when formal regulation is weak,[2] evidence from the empirical literature are mixed. For instance, Hartman et al. (1997) or Kathuria (2007) conclude that informal regulation has significant effects on pollution abatement effort of firms contrary to Pargal et al. (1997) or more recently to Cole et al. (2008) who have not been able to demonstrate any linkages between pollution emissions and informal regulation. Some empirical works are then still needed.

[1]See Anderson (2002) for a recent survey of incentive-based instruments for controlling pollution in developing countries.

[2]In Indonesia, the Environmental Impact Management Agency has created a program to rate factories based on their compliance with national wastewater discharge standards and to disclose the rating to the public. From 1995 to 1997, the firm compliance rate has increased from 35 percent to 51 percent.

This paper contributes to the literature trying to assess the impact of formal and informal regulations on environmental and economic performance of firms in developing countries. To address this issue, we estimate a cost function for a sample of Brazilian manufacturing.[3] To our knowledge, this is the first cost function estimate for the Brazilian manufacturing industry taking into account both the formal and informal environmental regulation framework. In order to investigate the impact of environmental regulation on the cost structure of Brazilian manufacturing plants, we adopt a dual approach where production technology is represented by a cost function, approximated by a translog form. Pollution is considered as a negative by-product that can be modified trough using either formal regulation (inspections or sanctions) or informal regulation (community pressure). A simultaneous equation model is estimated by three-state least squares on a sample of 404 industrial plants located in the state of São Paulo, Brazil. From a methodological point of view, we show that the endogeneity of the environmental regulation is a critical issue which can be addressed through the use of a simultaneous equation model estimated with 3SLS. The most important empirical findings are the following ones. First, pollution abatement costs for the Brazilian manufacturing sector are different from zero which suggests that pollution emissions are affected by environmental regulation. Second, environmental performance of firms is jointly affected by formal and informal regulation. Third, formal regulation is largely influenced by informal regulation and more specifically by community pressure.

The remainder of the paper is organized as follows. In Section 2, we summarize the literature dealing with the potential impact of environmental regulation (both formal and informal) on firm's environmental and economic performance. Section 3 presents the cost model we will estimate for firms under environmental regulation. Section 4 presents the empirical application to the manufacturing sector in Brazil. Then, we conclude briefly in Section 5.

[3] A recent example of cost function estimate including pollution emissions is Considine and Larson (2006).

2 Relevant literature

In this section, we review the empirical literature that has investigated the relationships between environmental regulation and economic or environmental performance of firms. We focus in particular on developing countries.

2.1 Environmental regulation and economic performance

There is a vast literature (both theoretical an empirical) trying to assess the relationship between environmental regulation and economic performance of firms. In a famous article published in 1991, Porter (1991) has suggested that "Strict environmental regulations do not inevitably hinder competitive advantage against foreign rivals; indeed, they often enhance it." The Porter's idea is that environmental regulation which reduces pollution damages can also lead to a decrease of costs and an increase in competitiveness of firms.[4] But this so-called "Porter hypothesis" has been recognized by many economists as clearly controversial. In particular Palmer *et al.* (1995) have raised severe arguments against it, first pointing out that the empirical evidence supporting Porter's hypothesis are quite weak. Second, from a theoretical point of view, the Porter's hypothesis presupposes that firms which were not maximizing their profit ex-ante behave optimally once the environmental regulation has been implemented. Last, most of the empirical studies are based on total factor productivity analyzes were the production is regressed on input shares.[5] The econometric specifications are however often very ad-hoc and the resulting estimates

[4] It has been for example suggested that German firms possess some competitive advantage in water-pollution control technology and US firms dominate hazardous waste management because of relatively stricter regulations. But the Porter's hypothesis itself is not very clear and different interpretations have been proposed. In particular, a "narrow version" which has given rise to a lot of empirical analyzes is that environmental regulation can stimulate innovation. Most of the empirical papers have tried to test this assumption by regressing some measure of innovation on pollution abatement capital. For instance, Jaffe and Palmer (1997) using a panel of data defined at the industry level estimate the relationship between pollution control expenditures and two measures of innovative activity (R&D expenditures and number of successful patents). They find that the data are consistent with the weaker version of the Porter hypothesis.

[5] Working on a sample of plants in the pulp and paper industry, Gray and Shadbegian (2003) find among others that total pollution abatement costs reduce productivity by an average 4.8 percent across all the plants.

may be subject to controversy and discussion. In particular, pollution abatement expenditures are often used to proxy the environmental regulation. This creates a number of difficulties. First, measuring specific pollution abatement expenditures is very difficult and this variable may suffer from a lack of precision. Second, it is likely that firms will first react to environmental regulation by adapting their existing production process. Reduction of pollution emission may not result, at least at the beginning of the process, in specific pollution abatement investments. In our framework, we use variables that are directly related to environmental regulation. It follows that our estimates should not suffer from the bias we have just depicted.

2.2 Environmental regulation and environmental performance

Formal regulation Formal environmental regulation corresponds to all kinds of mechanisms implemented by public authorities for regulating pollution emissions. Formal regulation schemes usually combine a system of standards for pollution emissions with a system of sanctions in case of non-compliance. Incentive-based instruments such as pollution, input or output taxes also belong to the formal environmental regulation since they are usually under the responsibility of public authorities.

In his survey of the literature on pollution control policies in developing countries, Blackman (2009) mentions that a vast majority of studies have found that formal environmental regulation is positively correlated with environmental performance. For instance, Aden et al. (1999) finds that regulatory actions have a significant reducing impact on pollution emissions of Korean manufacturing plants. Dasgupta et al. (2001) report that environmental performance of industrial polluters in China can be well explained by inspections conducted by the regulatory agency. For the Brazilian manufacturing industry, Seroa da Motta (2006) shows that formal regulation (sanctions and demands from regulators) are the most influential determinants in the adoption of good environmental practices. A few papers have concluded in the opposite direction. Schlottmann (1976), working on sulfur emissions in the US coal industry finds that regulation did not have any effect on pollution emissions. Blackman and Kildegaard (2010) reports that the number of inspections carried out by the environmental agency is not correlated with adoption of clean technologies in the Mexican leather tanneries. They however explain this result by the absence of real formal regulatory pressure.

The general conclusion is then that formal regulation (monitoring of emissions and enforcement of standards) appear to be a key determinant of environmental performance. Formal regulatory pressure drives environmental performance in developing countries despite conventional wisdom that such pressure is relatively low.

Informal regulation Informal environmental regulation corresponds to all types of actions taken by citizens, groups of citizens or Non-Governmental Organizations (NGOs) or by the market (consumers or investors) aiming at modifying the behavior of polluting firms. Typically, such actions include the pressure from communities and NGOs on polluting firms, the boycott of firm's products or the media coverage of environmental cases. Relying on informal environmental regulation is based on the idea that, in countries where enforcement of regulation is weak, firms may however comply with environmental standards because of informal regulation by local communities, Pargal and Wheeler (1996). Informal regulation may then emerge as a substitute to the deficient formal environmental regulation system.

Although Pargal and Wheeler (1996) mention that informal regulation may play an important role in developing countries, empirical evidence are mixed. Some articles conclude that environmental performance is related to the level of informal regulation. Hartman et al. (1997) use survey data on pulp and paper plants located in four different countries, namely, Bangladesh, India, Indonesia and Thailand. Informal regulation appears to be successful since "community pressure emerges as a clear source of interplant differences". In UK, Cole et al. (2005) using macro data for 22 industries covering the period 1990-1998, conclude that regulations, both formal and informal, have been successful in reducing air pollution intensity. Seroa da Motta (2006) assesses the determinants of environmental performance in the Brazilian industrial sector. His results suggest that indirect pressure from communities and NGOs is relevant to explain the environmental performance of firms. Kathuria (2007) analyzes the impact of informal regulation (media pressure) on water pollution control in Gujarat, the second most industrialized and polluted state of India. His analysis shows that local news coverage of pollution does have an influence on polluting behavior. Hence Kathuria (2007) suggests that lobbying efforts through the media may be quite effective in influencing industry behavior. For China, Zhang et al. (2008) have recently shown that informal regulation (pressures from supply chain, customers, and communities) plays a positive role in inducing firms to engage in effective environmental management policies.

On contrary Pargal et al. (1997), using survey data from India, conclude that there is no significant relationship between informal regulation and pollution discharge of plants. Cole et al. (2008) use Chinese industry specific emissions for a variety of pollutants between 1997 and 2003 to assess the linkages between pollution emissions and regulation. In their framework, formal and informal regulations are proxied by regional characteristics including regional's pollution prosecutions, unemployment rate, population density, age structure, and level of education. The majority of those variables appear to have no significant effect on pollution intensity. Lastly, Blackman and Kildegaard (2010) have identified the factors that drive the adoption of clean technologies for tanneries in León, Guanajuato (Mexico). They provide some negative evidence of the impact of informal regulation.

To conclude, it seems however that there are now enough evidence in the empirical literature to support the view that informal regulation affects significantly firm environmental performance, Blackman (2009).

Relationships between informal and formal regulation As noticed in Blackman (2009) formal and informal regulation mechanisms have spillover and feedback effects on each other, especially in developing counties.[6] This view was first defended by Pargal et al. (1997) who mention that formal regulation, especially the monitoring and enforcement of standards, tends to reflect the bargaining power of local communities and is not implemented uniformally. Cole et al. (2005) explain that the impact of informal regulation can be *indirect* if the community lobbies the local authority who then regulate the firm. A similar point has been made more recently by Kathuria (2007) who indicates that one reason that could explain that firms may react to informal regulation is the threat of increased intensity of formal regulation in case of bad environmental performance. This relationship between formal and informal environmental regulation raises some endogeneity concerns that will be addressed in the rest of the paper.

2.3 Environmental performance and economic/financial performance

Somehow related to our analysis is the literature having addressed the link between environmental regulation and financial performance of firms. Once again the link appears to be controversial since some authors report a negative relationship and other a positive one, see the meta-analysis Horváthová (2010). A recent example of this literature is Iwata and Okada (2011) who examine the effects of environmental performance on financial performance in the Japanese manufacturing industry. Although waste emissions do not generally have significant effects on financial performance, they report that on contrary greenhouse gas reduction leads to an increase in financial performance.

[6] It might be the case that community complaints incite formal regulatory pressure and vice versa.

3 A cost model with environmental regulation

3.1 Environmental regulation in Brazil[7]

Licensing is the main instrument for environmental management in Brazil. The licensing procedure sets up a wide scope of command-and-control mechanisms to be observed by industrial plants (abatement technology, emission standards and other control procedures). All industrial activities considered as a potential source of pollution or environmental degradation are required to possess such an environmental license.

Licensing is conducted by state environmental protection agencies (EPA). The process is divided in two stages. First, firms interested in constructing a production facility are required to apply for an installation license. Then, in order to start operations, they must possess an operation license. Operation licenses are issued after checking that the firm is in compliance with the environmental technical requirements, and they must be periodically renewed (2-5 years, depending on the sector of industrial activity). Firms may face two kinds of penalties for non-compliance: administrative sanctions imposed by the EPA, which are set on the basis of the magnitude of the offense, and/or legal sanctions imposed by the judiciary.

The licensing procedure has raised three types of criticisms. First, the procedure is subject to excessive delays. According to Couto (2003) "it is not uncommon to observe 5-year delays in the licensing of projects without any technical complexity". This is a particularly serious problem since plants operating without licenses are subject to fines. Secondly, there has been a discussion about the legal validity of the licensing procedure. Although the Brazilian National Environmental Law attributes the licensing process to the state EPA, a subsequent regulation has given to municipalities the power of granting licenses for industrial activities whose environmental

[7] For a more detailed description of the Brazilian environmental regulation framework, see Ferraz et al. (2002) and Seroa Da Motta (2003a).

impacts are locally restricted. This conflict has created additional costs, both in terms of financial resources and time, Vaz Guimarães De Araújo (2003). The third criticism of the Brazilian environmental licensing system is the budget and human resource constraints faced by EPAs resulting in a is quite asystematic monitoring of firms. In spite of the criticisms, the proportion of firms in a non-compliance situation concerning environmental licensing is relatively low[8], since the installation of a firm is easily spotted and licensing is mandatory in order to be eligible to governmental funds and to fiscal incentives.

Informal environmental also plays a significant role in Brazil and relies on the fact that, by Law, any citizen can act against polluters for noncompliance. Anyone can file a complaint against an alleged violator and community denouncement is very common in Brazil since it can usually be made by a telephone call. Moreover, once the case gets space in the news media, its priority on EPA strategies increases, Seroa Da Motta (2003b). This is consistent with the previous literature having demonstrated the existence of spillover and feedback effects between formal and informal regulation mechanisms, Blackman (2009). An example of the impact of informal regulation deals with Rio de Janeiro where the protest against a polluting tannery has led to its relocation to the outskirts of the city, Pargal and Wheeler (1996). NGOs are also frequently an important source of pressure to denouncement, particularly those that are locally organized.

3.2 A simple economic model

The model we consider can be derived from the general assumption that firms are minimizing their total production cost. We consider a firm using J inputs in order to produce two goods, Y_1 a production good sold by the firm and Y_2 representing the emitted pollution viewed as a

[8]As observed by Ferraz et al. (2002), plants failing to be fully licensed may operate within a grace period to realize some investments in order to conform to the licensed parameters. During this period, they are not legally considered as non-compliant.

joint product of the production good.[9] The emitted pollution could also be considered as a non-conventional input, but as we will show in this sub-section, such a formulation is equivalent to the one adopted above.

The production function denoted by f, $Y_1 = f(X, Y_2)$, possesses the usual characteristic of a neoclassical production function. Our implicit view is that by changing the mix of inputs, firms are able to reduce their pollution emissions while maintaining the production of Y_1 at a given level. The vector of inputs X may contain the usual inputs (capital, labor, material and energy) used for the production of the conventional output but also some inputs specific to pollution abatement processes. It is likely that some inputs are used directly for environmental compliance, a scrubber on a smokestack to reduce SO2 emissions is an example of such specific inputs.

Denoting by W the vector of input prices, the production expenses related to conventional inputs write $\sum_j W_j \cdot X_j$. But the firm also has to pay for its pollution discharge. Those expenses depend on the level of pollution emitted by the firm (Y_2) and on some characteristics of the formal environmental regulation under effect (R^{for}). The total expenses for pollution discharge write $\Phi(Y_2, R^{for})$. A firm will minimize the sum of its production costs and the emitted pollution costs. The resulting optimization program writes:

$$\begin{cases} \text{Min}_{X,Y_2} & \sum_j W_j \cdot X_j + \Phi(Y_2, R^{for}) \\ s.t. & Y_1 = f(X, Y_2). \end{cases} \tag{1}$$

The optimal use of inputs is such that marginal productivity of each factor is equal to its price and that the marginal productivity of pollution is equal to the marginal cost of emissions. In other word, the pollution emitted is such as the marginal benefit from another unit of abatement

[9] In a total productivity framework Boyd, Tolley, and Pang (2002) also consider pollution emitted by a firm as an undesirable output. Working on a sample of firms in the container glass industry, they show that there are opportunities both to improve productivity and to reduce pollution.

is equal to the marginal cost of that abatement. The first order conditions write:

$$\frac{\partial f/\partial X_j}{\partial f/\partial X_k} = \frac{W_j}{W_k} \text{ and } \frac{\partial f/\partial Y_2}{\partial f/\partial X_j} = \frac{\Phi'(Y_2, R^{for})}{W_j} \;\; \forall j,k \in \{1,\ldots,J\}, \tag{2}$$

where Φ' is the derivative of the pollution cost with respect to the pollution emitted. It follows that the input derived demands write as $X_j^*[Y_1, W, \Phi'(Y_2, R^{for})]$ and $Y_2^*[Y_1, W, \Phi'(Y_2, R^{for})]$. The resulting total cost we are going to estimate in the following sections may be written as:

$$TC(Y_1, Y_2, W, R^{for}) = \sum_j W_j \cdot X_j^*[Y_1, w, \Phi'(.)] + \Phi(Y_2^*[Y_1, W, \Phi'(.)], Z, R^{for}). \tag{3}$$

The resulting cost function depends on the output produced, the pollution emitted, the vector of conventional input prices and the formal environmental regulation under effect.

As discussed previously, consistent estimation of the cost model represented by Equation requires to solve some problems of endogeneity. First, one may expect that relatively dirty plants are more likely to be regulated by public authorities than clean ones, Blackman (2009). This raises an endogeneity issue for the formal regulation variables that will be introduced into the cost function. Second, in a country like Brazil, it is likely that formal regulation, especially the monitoring and enforcement of standards, will reflect the pressure of local communities which should be higher in case of very bad quality of the environment (high pollution emissions of the firm). This raises an endogeneity issue for the for the pollution emission variable. We address more formally these two issues in the next section.

3.3 Econometric model

To address the issue of simultaneity and potential endogenity of some variables, our econometric strategy is to estimate a system of simultaneous equations where production costs, formal regulation under effect and pollution emissions are the variables to be explained.

Cost function We assume that the unknown cost function (3.2) can be approximated by a flexible form. We use a translog form that gives a second order approximation to any unknown function. The translog form is flexible, parsimonious and satisfies price homogeneity assumptions, by imposing a set of linear restrictions on the parameters to be estimated. The translog approximation of (3.2) is[10]:

$$\begin{aligned}\ln(TC) = \quad & \alpha_0 + \sum_{l=1}^{2} \alpha_l \ln Y_l + \sum_{j=1}^{J} \beta_j \ln W_j + \frac{1}{2} \sum_{l=1}^{2} \sum_{m=1}^{2} \alpha_{lm} \ln Y_l \ln Y_m \\ & + \frac{1}{2} \sum_{j=1}^{J} \sum_{k=1}^{J} \beta_{jk} \ln W_j \ln W_k + \sum_{j=1}^{J} \sum_{l=1}^{2} \gamma_{jl} \ln W_j \ln Y_l + \sum_{s=1}^{S} \eta_s R_s^{for} + \epsilon \qquad (4)\end{aligned}$$

where indexes j, k with $j, k = 1, \ldots, J$, correspond to inputs and l, m with $l, m = 1, 2$, to outputs (production and pollution). R^{for} is a vector $S \times 1$ of variables describing the environmental formal regulation under effect (sanctions in case of non-compliance, inspection rate, ...). In Equation (4), ϵ represents the usual error term. From Shepard's Lemma, the cost shares S_{ji} can be written:

$$S_j(W, Y) = \frac{\partial \ln TC}{\partial \ln W_j} = \alpha_j + \sum_{k=1}^{J} \alpha_{jk} \ln W_j + \sum_{l=1}^{L} \gamma_{jl} \ln Y_l + \xi_j \quad j \in 1, \ldots, J. \qquad (5)$$

where S_{ji} represents the cost share of input j for firm i. In Equation (5), ξ_j represents the usual error term. Equation (4) associated to $J - 1$ cost shares constitutes the cost model to be estimated.[11] Since the cost function being twice differentiable, the Hessian matrix must be symmetric. The resulting symmetry restrictions are imposed on the coefficient to be estimate. Moreover, the cost function must be homogeneous of degree 1 in input prices. The following linear set of constraints will be imposed on the model to be estimated:

$$\sum_{j=1}^{J} \beta_j = 1, \quad \sum_{l=1}^{L} \gamma_{jl} = \sum_{j=1}^{J} \gamma_{jl} = 0.$$

[10] In the empirical part, we also have considered other specifications of the translog including for example cross-terms between environmental regulation variables, price of inputs and outputs. All these coefficients were not significant. For simplicity reasons, we only report the estimate of the translog where environmental regulation variables do not interact with input prices and outputs.

[11] As the sum of cost shares is equal to 1, only $J - 1$ cost shares must be taken into account otherwise the variance-covariance matrix would be singular.

Formal regulation As discussed previously, the formal regulation in Brazil is assumed to be (partially) driven by the pressure of local communities. We assume then that the vector R^{for} can be written as:

$$R_s^{for} = \sum_{v=1}^{V} \delta_{vs} R_v^{inf} + \zeta_s \quad s \in 1, \ldots, S. \tag{6}$$

where R^{inf} is a $V \times 1$ vector of variables representing informal regulation. This adds to the model a system of S equations to be estimated.

Pollution emissions Following Blackman (2009), we will assume that the environmental performance of firm (pollution emissions) can be explained by the intensity of formal and informal regulation under effect and by a vector of technical characteristics of the firm (size, location, vintage, etc.). The pollution emissions equation is then specified in the following way:

$$Y_2 = \theta Y_1 + \sum_{s=1}^{S} \mu_s R_s^{for} + \sum_{v=1}^{V} \rho_v R_v^{inf} + \sum_{q=1}^{Q} \kappa_q Z_q + \nu \tag{7}$$

where Z is a vector $Q \times 1$ including technical characteristics of the firm that may have an impact on pollution emission (industrial sector, location of the plant,...). In equation (7), the size effect is captured by the parameter θ associated with Y_1 (production level) and ν represents the error term.

The model to be estimated is then made of the system of simultaneous equations (4)-(7) corresponding to the cost function, the input cost share equations, the formal regulation equation and the pollution emission equation. To control for the endogeneity of formal regulation and pollution emissions, one may have used some two-stage least squares (2SLS), as done for instance by Aden et al. (1999) or by Dasgupta et al. (2000). Here, we will estimate this system of simultaneous equation with three-stage least squares (3SLS) since compared to 2SLS with instrumental approach, it allows to get efficiency gains (or cross-equation tests) with a consistent estimator of equations in case of endogenous regressors.

4 Empirical Analysis

4.1 Data description

The data used for estimating the cost function come from a survey jointly conducted by the Coordination of Environmental Studies of the Institute of Applied Economics Research (IPEA) at Rio de Janeiro and the Center for International Development at Harvard University (CID). The final database contains information on economic and environmental management practices for 404 industrial plants located in the state of São Paulo, Brazil (year 1999).

Cost data Table 1 presents some descriptive statistics on the production costs of of Brazilian manufacturing firms. It should be noticed that the survey realized by IPEA/CID has targeted large firms. The average production cost is larger than 17 millions of R$. On average the number of employees is 271 with a maximum equal to 4,861. With a cost share equal to 0.457, material is higher input in term of cost expenses.

[Table 1, about here]

The cost function includes five inputs namely capital, labor, energy, materials and water. The cost shares for labor, energy, materials are obtained directly from the questionnaires. Water expenses include water/wastewater costs and environmental control activities. The capital share is computed by summing up the depreciation and financial charges and the other capital expenses. The price of capital corresponds to the sum of the real interest rate and the depreciation rate. The latter was calculated by Muendler (2001) at sector-level, according to the Brazilian Census

Bureau (IBGE) classification. The price of labor is computed by dividing the total labor and social charge expenditures by the number of employees. For 84% of the sample, the unit cost of labor belongs to $[5,000; 25,000]$ which is a relevant range of values given the Brazilian yearly wage. Since the questionnaire does not include information on the quantity of energy used by plants, the price of energy corresponds to a weighted average of the price (per 10^6 Kcal) of oil, natural gas, electricity and coal computed at the sector-level. The weights are the respective shares in total energy use at sector-level as reported by the São Paulo Energy Survey, BESP (2000). A material price index has also been constructed at the sector-level using the input-output matrix computed by the Brazilian Census Bureau. Last, the water price is obtained by dividing the water/wastewater and the environmental expenditures by the total quantity of water consumed.

We have considered two different outputs, a measure of production Y_1 and a measure of plant effluents, Y_2. The physical measure of the output produced by the plant, Y_1, is computed by dividing the annual production value by the sectoral wholesale price index (IPA-FGV). The second output is a measure of effluent discharge, Y_2. The main empirical problem is that we do not observe directly this variable at plant-level.[12] In order to circumvent this data availability constraint, we follow Féres and Reynaud (2005) by constructing an effluent index based on a principal component analysis (PCA) performed on variables representing technical characteristics of the firm and on the subjective assessment of managers concerning firm's environmental performance. The idea of this procedure is that the non observable pollution emissions are a complex function of environmental regulation and of some technical characteristics of the firm. Realizing a PCA on these variables allows to extract this hidden information, the resulting Y_2 being interpreted as an index of effluent discharge. Robustness checks and a detailed presentation

[12] This is a pervasive problem in developing countries where plant-level monitoring of emitted pollution is at best imperfect, and where monitoring equipment is often obsolete.

of the pollution index can be found in Appendix A.

[Table 2, about here]

Formal environmental regulation It is likely that firms facing different formal regulatory regimes (especially environmental regulation) will have different allocations of inputs. Some variables describing the firm's regulatory environment are then introduced into the cost function. Three variables describe the formal environmental regulation. Most of existing studies in developing countries use a count of regulatory inspections and/or sanctions as a proxy of formal environmental regulation. Here we use the number of inspections conducted by the environmental agency between from 1997 to 1999 (variable $Inspect$). On average in our sample, firms have been inspected on average 4.30 times during that period but 150 firms have not been visited by the environmental agency. Variable $D_{license}$ is a dummy variable that describes the license status of the plant. It is equal to 1 if the license has been conditionally or fully approved by the environmental agency (392 firms in our sample). The third variable, $Control$, is a quantitative variable that measures the efficiency of the different regional environmental regulation agencies. It has been computed by dividing the total number of warning and fines delivered by an environmental agency by the total number of control realized by an agency in 1999. The average efficiency of regional environmental regulation agencies is 17.8% which means that 17.8% of controls realized by environmental regulation agencies have resulted in fines or warnings. We observe however significant differences across environmental agencies since the $Control$ variable varies from 5.5% to 22.3%. Among the three variables describing formal regulation, the one that is the most likely to be affected by endogeneity issue is the number of inspections by the environmental Agency. In the empirical model, we will then include a specific equation for this variable.

Informal environmental regulation Some previous works have shown that in countries where enforcement of regulation is weak, firms may however comply with environmental standards because of informal regulation by local communities, see Pargal and Wheeler (1996) for instance. Not introducing informal regulation would then lead to biased estimates.

Our first way to measure informal regulation is to proxy the effect of community pressure using a count of citizen complaints about pollution at a given plant or in a given location, Aden et al. (1999). The first variable (D_{comp}) we have considered is a dummy variable equal to 1 if some complaints from NGOs or local communities have been registered from 1997 to 1999. This variable was also used in Hartman et al. (1997) who considered complaints from local citizen groups concerning plant pollution as a determinant of pollution emissions. In our sample, 62 firms have been subject to some complaints, either from NGOs or directly from local communities. To capture the pressure of local communities, we have also considered the number of meetings organized with environmental NGOs, local community representatives or political representatives (variable $Meeting$). On average 3.51 meetings per firm have been organized between 1997 and 1999. Following Blackman and Bannister (1998), we have also proxied the effect of community pressure by introducing a variable representing for each firm that percentage of employees belonging to a trade union (variable $Union$). Hence, Blackman and Bannister (1998) have shown that, in Mexico, membership in a trade or community association can help explaining adoption of clean technologies by firms. In our sample, on average 40.06% of employees belong to a trade union.

It has been suggested that consumer pressure can influence plants' environmental performance in developing countries. To address this issue, we follow Seroa da Motta (2006) who test the effect on Brazilian manufacturing plants' environmental performance of exporting to countries in the Organization for Economic Cooperation and Development (OECD). The idea is that firms operating on international markets may be given more incentives to respect environmental standards.[13] Notice that Hartman et al. (1997) also include in their framework a similar variable, arguing that export-oriented plants might abate more because of sensitivity to "green consumerism" in richer importing economies. They were however not able to identify such an effect. Our variable (*Export*) is percentage of the production exported by the firm in 1999. In our sample, 203 firms export at least some part of their production. On average, they export 6.97% of their production. The effect of this variable on the production costs is a priori ambiguous since, due to high competition, firms operating on international markets may be more efficient than firms only operating on the Brazilian market.

Firm ownership has also been shown to be a strong determinant of environmental performance, even if empirical results contradict the conventional wisdom that foreign-owned firm are relatively clean, Blackman (2009). We have considered two variables, $Owner_{for}$ and $Owner_{bra}$, who respectively represent the share of capital owned by the private foreign and Brazilian sectors.

Technical characteristics We have introduced some technical characteristics of the plant that may have an effect on the economic or the environmental performance of a firm. First, we consider the certification status of the firm. We use the variable D_{iso9} which gives the certification status of the firms for the ISO 9000 norm. D_{iso9} is a dummy variable equal to 1 if the firm has been approved with respect to the IS0 9000 norm. Second, Blackman and Bannister (1998) have shown that human capital (measured by employee education level) was a strong determinant of environmental performance. We then introduce in our model a variable ($TrainingEnv$) representing the share of employees having followed a specific training for managing wastes. Last, in order to take into account some sectoral effects, we consider a set of dummy variables describing the type of industrial sector (chemical, electricity, food, metals, textile, other). The

[13] Firms operating on international markets may be more conscious of their public image than local firms.

sectoral dummy variables have been computed from the Brazilian classification of firms (Codigo Atividades nivel 80).

4.2 Estimation of the model

We have estimated the system of simultaneous equations (4)-(7) corresponding to the cost function, the input cost share equations, the formal regulation equation and the pollution emission equation. Various empirical specifications have been tested. We report in Tables 3 and 4 the model providing the best adjustment to the data while being quite parsimonious in terms of parameters to be estimated. Our system is finally made of seven equations: a cost function, four input cost shares (capital, energy, material and water), one formal regulation equation where the dependent variable in the number of inspections conducted by the environmental agency (variable *Inspect*) and the pollution emission equation (variable Y_2).

[Table 3, about here]

As mentioned previously, the system of simultaneous equations has been estimated with three-stage least squares (3SLS). We have first conducted some Hausman tests to detect the presence of endogenous relations among our dependent variables.[14] Using this test, we reject the null hypothesis of no endogeneity with respect to *Inspect* in the cost equation (t=1.68, p<0.09). We therefore conclude that 3SLS method is appropriated since OLS estimators are potentially biased and inconsistent. Before presenting the result of the estimate, one should finally mention that the usual identification conditions are satisfied in our system of equations.

[14] Those particular Hausman tests are fully described in Al-Tuwaijri, Christensen, and Hughes II (2004). They involve a two-stage procedure. In the first stage, each dependent variable is regressed on all of the predetermined variables in the system. In the second stage, each dependent variable is regressed on the righthand-side dependent variables, the predicted values of the right-hand-side dependent variables obtained in the first stage, and the respective predetermined variables for that equation. The significance of each predicted righthand-side dependent variable is then used as a test of endogeneity.

Cost function estimate We first report the cost function estimation in Table 3. Estimation of the informal regulation and the pollution emission equations follow in Table 4. The cost estimate seems to behave correctly with a quite good prediction power. The adjusted R^2 associated to the translog is 0.907. Before commenting on the cost function estimate, we must check that some regularity conditions are satisfied. The cost shares estimated by the 3SLS method are positive for all observations and the cost function is increasing with respect to input prices. Moreover, concavity is satisfied for most of our observations.

Next, we consider some restrictions on parameters that, if verified, would lead to biased estimations of the parameters of the cost function. We test, in particular, the hypothesis of unitary elasticity of substitution (UES), homotheticity of technology and Cobb-Douglas specification of costs. The first Wald test leads to the rejection of the hypothesis of homotheticity of production[15] which means that an increase in the level of outputs induces some changes in the relative shares of inputs. This result is important as it validates the cost-minimization program given by equation (1). If emissions of pollution were separable from the conventional production process, all cross-terms between Y_2 and input prices should be null. Second, we reject the unitary elasticity of substitution hypothesis which means that inputs are not separable.[16] Third, the use of a translog function is relevant since the Cobb-Douglas specification is rejected.[17] Finally, we have computed the cost elasticity with respect to the production output (Y_1) as: $\frac{\partial \ln TC}{\partial \ln Y_1}$. We find that the cost elasticity for the production Y_1 is equal to 0.89, meaning that a 1% increase of the production Y_1 results in a 0.89% increase of the cost (we reject constant returns to scale at 1%). The mean cost elasticity for the production Y_1 has been computed by type of industrial sector. It is interesting to notice that the cost elasticity of production is similar from one sector to another.

[15] $\chi^2(8)= 130.52$, $p<0.001$.
[16] $\chi^2(10)= 32.10$, $p<0.001$.
[17] $\chi^2(21)= 150.76$, $p<0.001$.

[Table 4, about here]

Environmental regulation and economic performance First, none of the three variables included into the cost function to capture the impact of formal environmental regulation appears to be significant. This suggests that plants which are regularly subject to the control of environmental agencies do not incur higher costs for being in compliance with environmental standards. One should however not conclude that formal environmental regulation does not affect the economic performance of firms. Hence, the absence of cost impact of regulation holds for a given level of pollution emissions. Environmental formal regulation might in fact induce firms to reduce their pollution emissions in a costly way. This is what we will check in the next paragraphs.

Second, most of parameters associated to Y_2 in the translog cost function are significant. The cost elasticity of pollution emissions is negative (-0.61 on average) and significantly different from zero. This indicates that a marginal reduction of the pollution has a significant cost-increasing impact. A reduction by 1% of pollution emissions requires an increase of the production costs by 0.61%. The negative cost elasticity of pollution emissions means that Brazilian firms face positive marginal emission costs and that environmental regulation (either formal or informal) has an impact on firm pollution emissions. Hence, in a world where firms face no environmental control (neither formal, such as taxes on emissions or environmental standards to comply with, nor informal such as local community pressure), the optimal level of emissions should be such that the marginal cost of production with respect to the emitted pollution is null. In a world where firms face some form of environmental regulation, they should equalize their marginal cost of production taken with respect to the emitted pollution to the marginal environmental cost.[18] We document here the existence of a positive and significant cost of pollution abatement

[18] A one unit increase in pollution emissions results in a decrease of the cost of production given by $\partial TC/\partial Y_2 < 0$

for the Brazilian manufacturing industry and we interpret this finding as the consequence of environmental regulation. This result is consistent with Seroa da Motta (2006) who reports that environmental performance in the Brazilian industrial sector is directly impacted by market incentives and environmental regulation. Those findings are also in line with Hartman et al. (1997) who have shown that environmental regulation has significant effects on pollution abatement effort in various Asian countries.

These results have been complemented by an analysis by industrial sector. It is interesting to notice that the cost elasticity with respect to the pollution emitted varies according to the industrial sector considered (the variability is much higher for the pollution than for the standard output produced by firms). Four sectors present cost elasticity with respect to the pollution significantly different from zero: electricity, chemical, textiles and other. One explanation could be that since these sectors are viewed as important pollution producers[19], implementation of environmental policy may be more stringent.

Environmental regulation and environmental performance The predictive power of the formal regulation and of the pollution emission equations is good, with a pseudo R^2 equal to 0.33 for both equations.

We find that human capital is a significant determinant of environmental performance. Hence, pollution emission decreases significantly with the share of employees having followed a specific training for managing wastes (variable $TrainingEnv$). This result is consistent with the finding of Blackman and Bannister (1998) or Dasgupta et al. (2000) who have shown that employee education level was a strong determinant of environmental performance.

The size of the firm seems also to be a significant variable both for explaining pollution emis-

and a marginal increase of the environmental control cost. At the optimum, these two quantities should be equalized by the firm. It follows that $-\partial TC/\partial Y_2$ can be interpreted as the marginal cost of pollution abatement.

[19]The electricity and the textile sectors present the highest water effluent indexes.

sions and formal regulation. Larger firms tend to be more often inspected by the environmental agency. Larger firms tend to emit significantly less pollution. Those firms might have more easily access to efficient environmental technologies. This result is consistent with the previous literature since among nine studies that have tested for the effect of plant size on environmental performance, all but one find that larger firms are cleaner, Blackman (2009).

Formal regulation has a direct impact on environmental performance since the coefficient associated with the number of inspections by the environmental agency ($Inspect$) is significant and negative. The mean elasticity of pollution emissions with respect to inspections is equal to -0.06 meaning that if the environmental agency increases by 10% its inspection rate, then the pollution emissions should be reduced by -0.6%. This finding is consistent with Seroa da Motta (2006) who report that Brazilian firms facing strong formal regulations (financial sanctions for instance) tend to adopt a greater number of environmental control procedures. Our result is also in line with most of the previous literature that has demonstrated the existence of a significant relationship between inspections and environmental performance of firms, Aden et al. (1999) or Dasgupta et al. (2001).

Consumer pressure (measured through the share of production exported, $Export$) does not appear to directly influence environmental performance of Brazilian firm. This is in line with the previous finding by Dasgupta et al. (2001) and Seroa da Motta (2006) respectively for the Mexican and the Brazilian manufacturing industries. On contrary firm ownership matters. The higher is the percentage of the firm owned by foreign private investors ($Owner_{for}$ variable), the lower is the level of pollution emissions. This contradicts Aden et al. (1999) who find that Korean plants' expenditures on pollution abatement is reduced significantly in case of foreign ownership.

Finally, formal regulation is largely influenced by informal regulation and more specifically by community pressure. Two of the three variables included to capture community pressure are significant with a positive sign. The number of inspections tend to increase in case of complaints from NGOs or local communities (variable D_{comp}) and with the number of meetings organized with environmental NGOs, local community representatives or political representatives (variable $Meeting$). For Brazil, our result complement the findings of Seroa da Motta (2006) who was "not able to verify whether the community demand is conveyed to firms directly or through regulators and prosecutors". In fact, by showing that informal regulation has a significant impact on formal regulation, we validate the guess of Seroa da Motta (2006) that the indirect way (through regulators and prosecutors) plays an important role in the Brazilian context. Our result is moreover consistent with Pargal et al. (1997) who mention that formal regulation (monitoring and enforcement of standards) reflects the bargaining power of local communities, with Dasgupta et al. (2000) who have shown that public scrutiny promotes implementation of stronger environmental policies in Mexico, or with Kathuria (2007) who indicates that one reason that could explain that firms may react to informal regulation is the threat of increased intensity of formal regulation in case of bad environmental performance. Moreover, the fact that formal regulation appears to be largely influenced by the community pressure validates our simultaneous equation approach and our estimation procedure (3SLS).

5 Conclusion

In this paper we have investigated the impact of formal and informal regulations on environmental and economic performance of Brazilian manufacturing firms. Adopting a dual representation of production technologies, we have estimated a Translog cost function using plant-level data for firms located in the state of São Paulo, Brazil. We think that assessing the impact of environmental regulation on environmental and economic performance of firms requires very detailed data (micro data) since pollution reduction investments or changes in the input mix can result from the pressure of local population, from the efficiency environmental regulation agencies or from both in the same time. It is likely that the impact of such important determinants may not appear at a more aggregate level, see Cole et al. (2008). This could explain the large range of results in the empirical literature focusing on the economic and environmental impacts of environmental regulation. From a methodological point of view, we have demonstrated that the endogeneity of the environmental regulation is a critical issue which can be addressed through the use of a simultaneous equation model estimated with 3SLS.

The most important empirical findings are the following ones. First, we find that formal regulation is largely influenced by informal regulation and more specifically by community pressure (complaints by local population, meetings with NGOs or local community representatives). To our best knowledge, this is the first time that such a relationship is formally identified in the Brazilian context. We then complement Seroa da Motta (2006) who was not able to show if community pressure has a direct impact on firm's pollution behavior or an indirect impact through strengthening of the formal regulation. Our result is consistent with the existing literature in developing countries showing that formal regulation (monitoring and enforcement of standards) often reflects the bargaining power of local communities, Pargal et al. (1997). This means that formal and informal environmental regulation should not be viewed as substitute policies. By favoring the development of local community pressure, one may expect a more stringent application of environmental norms by public authorities. Second, environmental performance of firms is jointly affected by formal and informal regulation. In line with most of the existing literature, we have found that a significant positive relationship between the number of inspections by the environmental regulation agency and the environmental performance of firms, Aden et al. (1999) or Dasgupta et al. (2001). Firm ownership also matters. Firm owned by foreign private investors have a level of environmental performance significantly higher. Human capital and the size of firms also appear to be some significant determinants of environmental performance. Third, we have shown that pollution abatement costs for the Brazilian manufacturing sector are significantly different from zero which suggests that pollution emissions are affected by environmental regulation (either formal or informal). This is especially true for the most pollution-intensive sectors like electricity and textile. This suggests that there is a great scope for welfare gains by reinforcing the environmental control activities in place, since a reduction of pollution emissions can be achieved without important production cost increases.

As mentioned previously, on challenge for establishing a clear link between environmental regulation (both formal and informal) and firm's pollution behaviors is to have access to detailed and accurate micro data. This is especially important in developing countries where social costs of pollution can be very high due to high population density nearby industrial plants. More efforts should then be put into the development of such databases.

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A Derivation of the Effluent Discharge Index

The PCA is based on 6 variables possibly correlated to pollution emissions. First, we use the total quantity of water consumed by the plant. This variable is introduced in order to make the water effluent index depend on the quantity of water use. Second, we use the firms's self-evaluation of environmental compliance status. This variable takes values $\{1, 2, 3, 4, 5\}$ respectively if the firm always fails, regularly fails, periodically fails, just meets or exceeds the environmental requirements. This variable should be negatively correlated with the water effluent index. Third, we use firms's environmental preferences. This variable is equal to $\{1, 2, 3\}$ respectively if environmental protection is not important, is important or is very important for the plant manager. Firms's environmental preferences should be negatively correlated with the water effluent index. Fourth, we introduce a dummy variable equal to 1 if the industrial possesses an environmental unit. Fifth, we consider the certification status of the firms for ISO 14000. This variable takes the values $\{1, 2, 3, 4\}$ respectively in case of no license yet, beginning licensing process, approved with conditionality and fully approved. The certification status should be negatively correlated with the water effluent index. Last, we use a dummy variable equal to 1 if the industrial self-reports water effluents to the environmental agency.

The first component explains 32.8% of the total variance and almost 50% of the variance is captured by the two first components. The first axis is highly positively correlated with the fact that the industrial plant possesses an environmental unit, with firms's environmental preferences, with certification status of the firms for ISO 14000 and with self-reporting by the firm to the environmental agency of water effluents. The Pearson correlation coefficients between the first component and these four variables are respectively 0.76, 0.53, 0.65 and 0.72. This first component is an index that measures the best environmental practices of plants (using objective characteristics such the ISO norm status and subjective characteristics such environmental preferences) related to water use. Firms with high first component values correspond to plants with high environmental performance, as verified by the positive correlation between the first component and variables entering the PCA. The effluent discharge index, Y_2, is then defined as the negative of the first component. Last, this index is re-scaled in order to be greater than one (the cost function requires to take the logarithm of all outputs) for all observations (the minimal value plus one has been added to $-Y_2$). This approach assumes implicitly that water effluents are inversely correlated with the measure of best environmental practices of plants given by the first component.

As we do not observe the true water effluents of plants, we can not explicitly evaluate our method. However, some robustness tests can be conducted. An output-pollution matrix, which relates effluents (both for organic charge, MO, and total suspended solids, TSS) to production, has been computed at the sectoral level by the Brazilian-French cooperative project on the Paraíba do Sul river basin. The coefficients of this matrix, based on the French Water Agencies' matrices, have been further calibrated in order to account for Brazilian technological specificities. They are presented in Cooperação-Brasil-França (1994). Using the Brazilian sectoral output-pollution matrix, we have computed the theoretical effluents. As expected, our effluent index is positively and significantly correlated with the theoretical MO and TSS emissions. The correlation coefficient between Y_2 and TSS is equal to 0.36. The correlation coefficient between

Y_2 and MO is equal to 0.32. This result tends to indicate that Y_2 is a reliable proxy of the non-observed water effluents.

Table 1: Descriptive statistics, costs and inputs

Variable	Definition	Mean	Std. Dev.	Min.	Max.
TC	Total Cost (10^3 R$)	17226	32408	100	289800
Y_1	Production (index)	117.119	230.587	2.092	2146.769
Y_2	Pollution (index)	4.822	1.402	1.000	7.738
S_k	Capital cost share	0.200	0.125	0.005	0.875
S_l	Labor cost share	0.297	0.150	0.037	0.917
S_e	Energy cost share	0.039	0.037	0.000	0.255
S_m	Material cost share	0.457	0.170	0.010	0.954
S_w	Water cost share	0.006	0.012	0.000	0.150
W_k	Capital unit price (R$ by 10^3 R$)	9.983	7.877	148	213
W_l	Labor unit price (R$ by employee)	14394	7984	3111	47806
W_e	Energy unit price (R$ by 10^6 Kcal)	6.946	0.902	4.071	8.107
W_m	Material unit price (R$ by unit of material index)	8.624	5.723	24.402	63.786
W_w	Water unit price (R$ by m^3)	3.675	1.954	0.004	9.709
X_k	Quantity of capital (10^3 R$)	25573	66189	12	954894
X_l	Quantity of labor (Number of employees)	271	475	6	4861
X_e	Quantity of energy (10^6 Kcal)	94882	210450	10	2261891
X_m	Quantity of material (Index)	307758	641218	167	5917206
X_w	Quantity of water (m^3)	51438	176737	6	1560000

Table 2: Descriptive statistics for environmental regulation and firm's technical characteristics

Variable	Definition	Mean	Std. Dev.	Min.	Max.
Formal regulation					
$Inspect$	number of inspections	4.30	9.77	0	150
$Control$	regulation efficiency	0.18	0.06	0	0
$D_{license}$	dummy if licence approved	0.97	0.17	0	1
Informal regulation					
D_{comp}	dummy for complaints	0.15	0.36	0	1
$Meeting$	number of meeting	3.52	15.17	0	198
$Union$	employees in trade unions (%)	40.06	36.41	0	100
$Export$	exported production (%)	5.98	12.66	0	100
$Owner_{bra}$	private brazilian ownership (%)	80.47	39.09	0	100
$Owner_{for}$	private foreign ownership (%)	19.36	38.89	0	100
Technical characteristics					
D_{Iso9}	dummy for iso 9000 norm	0.61	0.49	0	1
$TrainingEnv$	share of employees with env. training	0.18	0.33	0	1
D_{ele}	dummy for electric sector	0.14	0.35	0	1
D_{che}	dummy for chemical sector	0.10	0.30	0	1
D_{tex}	dummy for textile sector	0.20	0.40	0	1
D_{foo}	dummy for food sector	0.04	0.21	0	1
D_{met}	dummy for metal sector	0.17	0.37	0	1
D_{oth}	dummy for other sector	0.35	0.48	0	1

Table 3: Estimate of the translog cost function (3SLS)

(dependent variable TC)					
Variable	Coefficient	(Std. Err.)	Variable	Coefficient	(Std. Err.)
Y_1	0.888**	(-0.023)	Y_1Y_1	0.001	(0.002)
Y_2	-0.613**	(-0.212)	W_kY_1	0.011†	(0.006)
W_k	0.201**	(-0.006)	W_lY_1	-0.044**	(0.008)
W_l	0.292**	(-0.008)	W_eY_1	-0.005*	(0.003)
W_e	0.040**	(-0.003)	W_mY_1	0.039**	(0.008)
W_m	0.460**	(-0.008)	W_wY_1	-0.001	(0.001)
W_w	0.007**	(-0.002)	Y_2Y_2	-0.043	(0.039)
W_kW_k	0.084†	(-0.045)	W_kY_2	-0.042	(0.027)
W_kW_l	-0.023*	(-0.011)	W_lY_2	0.08*	(0.034)
W_kW_e	0.028	(-0.02)	W_eY_2	-0.029**	(0.011)
W_kW_m	-0.088*	(-0.036)	W_mY_2	-0.015	(0.033)
W_kW_w	-0.001	(-0.005)	W_wY_2	0.007	(0.006)
W_lW_l	0.028**	(-0.008)	Y_1Y_2	-0.09*	(0.045)
W_lW_e	-0.001	(-0.004)	$Control$	-0.493	(0.338)
W_lW_m	-0.007	(-0.013)	$D_{License}$	-0.019	(0.104)
W_lW_w	0.004	(-0.002)	$Inspect$	-0.002	(0.003)
W_eW_e	-0.017	(-0.013)	D_{ele}	-0.247**	(0.070)
W_eW_m	-0.011	(-0.014)	D_{che}	-0.47**	(0.073)
W_eW_w	0.001	(-0.002)	D_{tex}	-0.038	(0.065)
W_mW_m	0.111**	(-0.038)	D_{foo}	0.189	(0.116)
W_mW_w	-0.004	(-0.005)	D_{oth}	-0.165**	(0.056)
W_wW_w	0.000	(-0.001)	$Intercept$	15.99**	(0.132)
			R^2		
Cost Equation			0.907		
"Capital" cost share			0.060		
"Energy" cost share			0.053		
"Material" cost share			0.100		
"Water" cost share			0.110		

***, **, * respectively significant at 1%, 5% and 10%

Table 4: Estimate of the formal regulation and the pollution emission equations (3SLS)

Formal regulation equation (dependent variable $Inspect$)		
Variable	Coefficient	(Std. Err.)
Y_1	0.979**	(0.372)
D_{comp}	2.791*	(1.120)
$Export$	0.017	(0.034)
$Union$	0.007	(0.011)
$Meeting$	0.322**	(0.027)
$Owner_{bra}$	0.013	(0.117)
$Owner_{for}$	0.004	(0.118)
D_{ele}	-3.520*	(1.455)
D_{che}	-1.376	(1.621)
D_{tex}	-2.614*	(1.331)
D_{foo}	-2.143	(2.168)
D_{oth}	-3.105**	(1.204)
$Intercept$	0.787	(11.812)
Pollution emission equation (dependent variable Y_2)		
Variable	Coefficient	(Std. Err.)
Y_1	-0.060**	(0.014)
$Inspect$	-0.012**	(0.002)
D_{Iso9}	-0.122**	(0.029)
$TrainingEnv$	-0.198**	(0.041)
$Export$	-0.001	(0.001)
$Owner_{for}$	-0.001**	(0.000)
D_{ele}	0.037	(0.049)
D_{che}	-0.016	(0.055)
D_{tex}	0.001	(0.046)
D_{foo}	-0.203**	(0.074)
D_{oth}	0.008	(0.041)
$Intercept$	0.200**	(0.045)
		$\bar{R}^2$
Formal regulation equation		0.328
Pollution emission equation		0.331

***, **, * respectively significant at 1%, 5% and 10%