Assessing the Impact of Environmental Regulation on Industrial Water Use: Evidence from Brazil*

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Abstract

This paper aims at characterizing water demand by Brazilian manufacturing plants and at assessing the potential impacts of environmental policies on industrial water use. We first show that the price elasticity of the water demand, -1.0 on average, is high enough for a water charge to act as an effective policy tool for reducing water consumption. Results also provide some evidence of a tradeoff between water quality improvement and water conservation policies, since more stringent environmental standards may lead to a higher water demand. A joint use of environmental norms and water charges may reconcile both policy goals.

Keywords: Industrial Water Demand, Structure of Costs, Environmental Regulation, Brazil.

JEL Codes: Q21, Q25, L5.

I. INTRODUCTION

It is surprising to notice that while there is a considerable empirical literature focusing on residential and agricultural water demands, only a few works have been devoted to industrial water use.[1] Meanwhile, several questions related to the role of water in industrial applications remain unanswered. Little is known about how water enters into the production process and the substitution possibilities between water and other production inputs. Similarly, only a handful of studies have addressed the issue of environmental regulation impacts on industrial water use. This lack of information is particularly noticeable in the case of developing countries, the vast majority of existing analyses dealing with North-American and Western European countries.

Yet, several reasons speak in favor of studying industrial water demand and its interaction with environmental policies. Industrial withdrawals represent an important part of total extracted water in most countries and it is viewed as a major source of pollution. As water quality problems are expected to be more severe in the next years, more stringent industrial water regulation is required. This is especially true in developing countries where populations live in the vicinity of industrial areas and suffers from high pollution levels. Moreover, since a number of developing countries are moving from an historical environmental regulation based on a "command and control approach" toward more incentive-based instruments like pollution taxes, estimating industrial water demand function has become a major concern in water management policy.

This paper aims at characterizing Brazilian manufacturing plants water demand, and at assessing the potential impact of environmental policies on industrial water use. Focusing on Brazil is interesting for several reasons. First, numerous reforms on the country's water management system are under way. The Federal Water Law of January 1997 introduced quality and quantity-related water charges in the regulatory framework, which are currently being designed and implemented in several river basins. Second, rapid population and industrial growth have generated water scarcities in some urban areas, especially due to water quality deterioration. In a context where one expects the introduction of more stringent environmental norms and new policy instruments, it seems important to assess the impact of environmental policies on water users. Last, our application to Brazil represents the first econometric analysis of industrial water demand in a Latin-American country.

Estimating industrial water demand requires to fully identify the cost structure of firms as water can be viewed as an input of the production process. As effluent control decisions cannot be considered a priori separable from production decisions, effluents must also enter the production function. However, a pervasive problem faced by developing countries is that, due to the lack of pollution monitoring systems, plant-level effluents are not systematically measured. We will show how an index measuring effluent discharge can be constructed in order to circumvent this problem. We are especially interested in answering the three following questions. First, how does water enter the production function and what are the complementarity or substituability relationships between the different inputs? Second, what can be said about the price elasticity of industrial water demand in Brazil? Third, what are the effects of environmental policy instruments (water charge or environmental norm) on firms' costs and input choices?

The remainder of the paper is organized as follows. In Section 2, we review the main findings of the applied literature dealing with industrial water demand. Section 3 presents the economic and econometric modeling together with the empirical application. Last, Section 4 addresses more carefully the way water enters the production process and analyzes the consequences of public authority intervention on firms production decision choices and on costs.

II. INDUSTRIAL WATER DEMAND: A BRIEF SURVEY

Most of the published studies have focused on two related issues: the price elasticity of industrial demand and the substituability/complementarity relationships between water and the conventional inputs. Grebenstein and Field (1979) and Babin, Willis, and Allen (1982) study water demand of the manufacturing industry in the United States. Both works estimate a translog cost function using aggregate data. Grebenstein and Field (1979) compute price elasticity values ranging from -0.33 to -0.80, depending on the water price specification adopted. The authors show that water and labor are input substitutes whereas capital and water are complements. Babin, Willis, and Allen (1982) find that price elasticity varies considerably across sectors, ranging from 0.14 for the food industry to -0.66 for the paper and wood industry. Substitution possibilities between water and other production inputs also depend on the industrial sector. Renzetti (1988) provides a deeper investigation of the role of water in industrial plants by breaking down water use into four components: intake, pre-treatment, recirculation and discharge. According to the sector considered, price elasticity varies from -0.54 to -0.12. The author finds that water intake and recirculation are substitutes, providing some evidence that intake water charges may induce water use efficiency.[2] Dupont and Renzetti (2001) extend the previous analysis by incorporating information on other production inputs than water. They show again that water intake is a substitute to water recirculation, as well as to energy, labor and capital. Last, Reynaud (2003) investigates the structure of industrial water demand in France. Elasticity values are generally in line with the ones found for US and Canadian firms, varying from -0.10 to -0.79 across activities.

Due to data availability problems, studies on industrial water demand in developing countries are particularly scarce and have just recently started. Wang and Lall (1999) is the first econometric analysis applied to a developing country. They use plant-level information on approximately $1,700$ Chinese industrial plants. In contrast to previous works, based on a dual cost function estimation, Wang and Lall (1999) adopt a marginal productivity approach and they find an average price elasticity around -1.0, a higher value than those reported for developed countries. Onjala (2001) analyzes industrial water demand in Kenya. The author estimates a single water demand equation based on a dynamic adjustment specification. The estimated price elasticities range from -0.60 to 0.37.

The main results of these studies are the following. First, price elasticities are small but in general higher than domestic ones. Second, estimates strongly depend upon the industry considered. Third, water and labor are mostly substitutes whereas capital and water are complementary inputs. Moreover, excepting Reynaud (2003), none of these papers integrates effluent emissions when estimating the industrial cost function. The implicit assumption is that production and water pollution control decisions are separable. This seems to be a strong assumption, as Reynaud (2003) tests and rejects this separability hypothesis. In what follows, by considering effluent discharge as a joint negative output of the production process, we can assess the impact of environmental regulation on firms' production decisions.

III. COST FUNCTION ESTIMATE OF BRAZILIAN FIRMS

A Translog Specification of Costs

Assessing how water enters the production process of a firm requires to specify the production technology. We represent firm's production technology by the long-term cost function:

$$TC(W, Y; Z) = \left\{ \min_X \sum_{j=1}^{J} W_j X_j \;\mid\; X \in V(Y; Z),\;\; W > 0_J \right\} \qquad [1]$$

where X is the vector $(J \times 1)$ of inputs with an associated price vector W, Y a vector $(L \times 1)$ of outputs and $V(Y; Z)$ the production set. The vector Z $(Q \times 1)$ corresponds to technical characteristics of the firm that may have an impact on its cost structure. The unknown cost function defined by [1] is approximated by a translog form:

$$
\begin{aligned}
\ln(TC_i) =& \alpha_0 + \sum_{l=1}^{L} \alpha_l \ln Y_{li} + \sum_{j=1}^{J} \beta_j \ln W_j + \sum_{q=1}^{Q} \gamma_q Z_{qi} + \frac{1}{2} \sum_{l=1}^{L} \sum_{l'=1}^{L} \alpha_{ll'} \ln Y_{li} \ln Y_{l'i} \\
&+ \frac{1}{2} \sum_{j=1}^{J} \sum_{j'=1}^{J} \beta_{jj'} \ln W_{ji} \ln W_{j'i} + \frac{1}{2} \sum_{q=1}^{Q} \sum_{q'=1}^{Q} \gamma_{qq'} Z_{qi} Z_{q'i} \\
&+ \sum_{j=1}^{J} \sum_{l=1}^{L} \mu_{jl} \ln W_{ji} \ln Y_{li} + \sum_{j=1}^{J} \sum_{q=1}^{Q} \nu_{jq} \ln W_{ji} Z_{qi} + \sum_{l=1}^{L} \sum_{q=1}^{Q} \eta_{jq} \ln Y_{li} Z_{qi}
\end{aligned} \qquad [2]
$$

where $i = 1, \ldots, N$ represents firms. Indexes j, j' with $j, j' = 1, \ldots, J$ correspond to inputs, indexes l, l' with $l, l' = 1, \ldots, L$ to outputs and q, q' with $q, q' = 1, \ldots, Q$ to technical characteristics included in vector Z. From Shepard's Lemma, cost shares S_{ji} can be written:

$$
S_{ji}(W, Y) = \frac{\partial \ln TC_i}{\partial \ln W_{ji}} = \beta_j + \sum_{j'=1}^{J} \beta_{jj'} \ln W_{ji} + \sum_{l=1}^{L} \mu_{jl} \ln Y_{li} + \sum_{q=1}^{Q} \nu_{jq} Z_{qi} \quad j \in 1, \ldots, J. \qquad [3]
$$

S_{ji} represents the cost share of input j for firm i. Equation [2] associated to $J - 1$ cost shares constitutes the economic model to be estimated.[3]

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 database contains information on economic and environmental management practices of 500 industrial plants in the state of São Paulo, Brazil, for year 1999. Due to missing information, only 404 observations have been used.

Cost shares and input prices. The cost function includes five inputs: capital, labor, energy, materials and water (the usual KLEM model plus a water input). In filling out the questionnaires, firms were asked to report the share of total expenditures for the following components: depreciation, financial expenditures, labor, materials, energy, environmental control activities, water/wastewater and other capital expenditures. 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 other component shares (depreciation, financial charges and 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 is computed at the sector-level. It corresponds to a weighted average of the price (per 10^6 Kcal) of oil, natural gas, electricity and coal. 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 IBGE. Last, the water price is obtained by dividing the water/wastewater and the environmental expenditures by the total quantity of water consumed. The high price dispersion can be explained by differences in water quality needs and in wastewater treatments across industrial sectors.

Outputs. The multi-output cost function includes 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.[4] In order to circumvent this data availability constraint, researchers have developed two approaches. The first one consists in estimating the effluent discharge from a matrix relating effluents to the level of output. Such a matrix is usually defined at the industrial sector level.[5] There are two main problems with using such an approach in our case. First, the two variables Y_1 and Y_2 will suffer from a high level of collinearity. Second, effluents will represent an average level for the industrial sector considered. The implicit underlying assumption is that there is no heterogeneity in terms of pollution control between plants within the same sector. As we are especially interested in assessing the impact of environmental regulation on costs and pollution control, we can not rely on such an assumption. As mentioned in Ferraz et al. (2002), a second approach could be to use some measures of the plant environmental performance (such as the existence of ISO 14000 standard[6] or the result of an environmental audit) supposed to be correlated with effluent level. The choice of the proxy is crucial and, at least, some sensitivity analyzes are required. Ferraz et al. (2002) have used the annual level of environmental investment as a proxy for the pollution emissions. The main problem with this proxy variable is that environmental investment may not result in an immediate reduction of pollution emissions.

Our approach consists in defining 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 reasoning underlying this procedure is that the non-observable effluents depend on firm's environmental preferences and on some technical water-related characteristics of the production unit. Performing a PCA on these variables allows to retrieve this hidden information, the resulting Y_2 being interpreted as an index of effluent discharge. A complete presentation of the effluent index computation can be found in the appendix.

Table 1 presents some descriptive statistics on the production costs of industrial firms. It should be noticed that the survey realized by IPEA has targeted large firms. The average production cost is larger than 17 million 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 the most important input in terms of cost expenses whereas water represents on average less than 1% of cost expenses.

Regulation and technical characteristics of firms. In spite of the recent introduction of economic instruments in the regulatory framework, licensing remains the main mechanism 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). The Brazilian licensing procedure has raised two 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". Second, there has been a conflict between municipalities and the State to decide who is in charge of implementing the licensing process. In spite of these criticisms, the proportion of firms in a non-compliance situation with environmental licensing is relatively low. This apparent contradiction can be explained by a large share of firms being in a particular "conditional status" authorized by the Brazilian environmental legislation. As observed by Ferraz et al. (2002), plants failing to be fully licensed may operate within a grace period in order to realize some investments and to conform to the licensed parameters. During this period, they are not legally considered as non-compliant.

Firms may face two types of penalty for non-compliance with the norms and emission levels mandated by the environmental licensing: administrative fines and/or legal sanctions.

In order to assess the effects of environmental regulation on the cost structure and input mix, two variables describing environmental regulation are introduced in the cost function, see table 2. D_{INS3} is a dummy variable equal to one if the plant has been inspected each year from 1997 to 1999 by the environmental agency. Regular inspections usually target the most important pollution intensive sectors. As fine enforcement for non-compliant firms is weak, as it will be discussed later, we expect a non positive sign associated to D_{INS3}. D_{SAN3} is a dummy equal to one if the industrial has been sanctioned at least once from 1997 to 1999 by the environmental agency. This variable refers to administrative fines which may range from simple warnings to financial compensations. Firms sanctioned may have found more cost-effective not to comply with environmental standards. This variable should have a negative sign. A variable related to environmental management practices has also been considered. D_{UNIT} is a dummy variable equal to 1 if the plant possesses an environmental unit (monitoring network of effluents, end-of-pipe environmental unit...). Such a plant should have higher production costs, everything being equal. Finally, in order to take into account heterogeneity across activity sectors, we also consider sectoral dummy variables. The 28 activities of the Brazilian national accounting system have been grouped into 6 sectors: *Chemical*, *Electric*, *Food*, *Metals*, *Textiles*, all remaining activities being grouped in *Other*.

Cost Function Estimate

The system of equations composed by the cost function [2] and the $J-1$ cost shares [3] has been estimated by Seemingly Unrelated Regression (model SUR). The symmetry and price homogeneity constraints have been imposed using the usual parametric restrictions. The estimated parameters of the translog cost function are given in table 3.[7]

Cost specification issues. The cost estimate seems to behave correctly with good prediction power. The adjusted R square associated to the translog is 0.906. Before commenting on the cost function estimate, we must check that some regularity conditions are satisfied. First, we have computed the bordered hessian (evaluated at the mean of the estimated factor shares). All eigenvalues but one are negative, indicating that the estimated cost function possesses relatively good concavity properties. Next, using Wald tests, we test and reject the homotheticity hypothesis[8], which means that an increase in output levels induces changes in the relative input use ratios. Effluent control is not separable from the conventional production process since some cross-terms between Y_2 and input prices are significantly different from zero. This result is important as it validates the cost-minimization program given by equation [1]. We also reject the hypothesis of a unitary elasticity of substitution[9] which means that inputs are not separable.

Cost elasticities. First, we compute and analyze the cost elasticity with respect to the production Y_1 and to the effluent index, Y_2. The cost elasticity with respect to output $i \in \{1, 2\}$ is given by $\partial \ln TC / \partial \ln Y_i$. The cost elasticity for the production Y_1 is equal to 0.91, meaning that a 1% increase of the production Y_1 results in a 0.91% increase in costs. This provides some evidence of increasing returns to scale, further reinforced by the rejection of constant return to scale at 1% significance level. At the mean sample, the cost elasticity for the effluent discharge index, Y_2, is -0.16. In spite of the expected negative sign, we cannot reject the hypothesis that this cost elasticity is equal to zero. This result suggests that a marginal reduction of industrial effluents can be achieved without a substantial cost increase. Notice however that the elasticity differs across activities, varying from -0.07 for the Food industry to -0.18 for the Electricity sector, where this value appears to be significantly different from zero.[10] At the sample mean the marginal cost of a reduction in the effluent index is equal to 9,670 R$, a very low figure compared to the average cost of production.

Regulation and environmental management variables. Most regulation and environmental management variables entering the cost equation are not significant, which would indicate that environmental constraints have only a limited impact on costs.[11] The only significant variable is D_{UNIT}, indicating that the presence of an environmental unit is cost-increasing. This suggests that undertaking environmental-related actions is costly for firms.

On the other hand, the lack of significance of D_{INS3} and D_{SAN3} provides some evidence of a limited impact of environmental regulation variables on costs. This result may have two interpretations. First Brazilian environmental regulation may be stringent enough but may suffer from weak enforcement: although monitoring activities by the Brazilian Environmental Protection Agency (EPA) are rather intense, as shown by the high percentage of plants that have been systematically inspected (see table 2), firms may find more profitable not to comply with environmental regulation. This argument is supported by Ferraz et al. (2002), who observe that "firms have the incentive to avoid payment of administrative fines since collection of those fines are rather weak". Actually, environmental fines are collected by the State Treasury but allocated to the EPA's budget in São Paulo. So, collection effort by the Treasury does not increase its own resources, and there is no systematic process by which EPA can monitor the Treasury's collection efforts. An alternative interpretation is that the existing environmental regulation is not enough severe to have a significant impact on firms'costs.

Input Cost Share Estimates

Cost share specification issues. Cost monotonicity in input prices has been examined by considering the estimated cost shares for each industrial firm. For capital, labor and material inputs, the cost shares are positive for all observations. For energy and water inputs, respectively 4 and 19 observations have negative (but very low) cost shares. The cost monotonicity requirement in input prices is largely satisfied. Moreover, the estimated cost shares present a relatively good adjustment to observed data, the adjusted R-square being higher than 0.2 for all equations.

Effluent discharge and input use. First, the significant and positive coefficient for Y_2 in the materials share equation (see table 4) indicates that more polluting plants tend to be more material-intensive. This is quite intuitive, since materials-intensive production tends to produce a greater volume of waste residuals, and so to be more pollution-intensive. A deeper analysis would require more detailed data on inputs included in the material expenses. For the four other equations the effluent index coefficient is negative but not significantly different from zero. Capital-intensive plants seems to produce lower effluent discharge. This can be the result of more investments in effluent abatement equipment or use of modern, high-valued equipment which embodies more effective pollution control technologies. The finding that more labor-intensive plants produce less effluent discharge may be due to the fact that they are subject to more strict environmental control by environmental agencies.

Effect of regulation on input mix. Globally, the effect of regulation on production decision (input mix) is very limited as only a few variables appear to be significant. D_{SAN3} is significant with a negative sign in the capital equation: sanctioned firms tend to have lower capital shares than firms complying with environmental standards. This suggests that capital investment may be a way of reducing effluent discharge. It is however interesting to have a closer look at the signs associated to regulation variables in the cost share equations. Let us first consider the presence of an environmental unit in the plant D_{UNIT}. Industrial firms possessing such an environmental unit tend to have higher capital cost shares and lower cost shares associated to other inputs: they are substituting capital to other input. Firms under close monitoring (D_{INS3} equal to 1) have higher capital and labor cost shares and lower energy and material cost shares. The positive coefficient associated to D_{INS3} in the labor equation is in particular very high: firms under close monitoring by the environmental agency use more labor. This could reflect environmental agency monitoring practices: very often monitoring efforts target large firms measured in term of number of employees. Globally, firms under more stringent environmental regulation tend to substitute capital and labor to energy and material, increasing abatement activities and reducing waste residual production. To conclude: (1) environmental regulation is not stringent enough to have a significant and clear impact on firms'allocation of inputs (regulation variables are not significant). (2) As all coefficients have the expected signs, reinforcing environmental regulation may have a significant impact on pollution control. The negative sign associated to effluent discharge in the capital and labor cost share equations is another evidence of this.

IV. WATER USE AND ENVIRONMENTAL POLICIES

Substituability Between Water and the Conventional Inputs

The cost function estimate enables us to derive the cross and own price elasticities. Table 5 presents the mean of these elasticities. All own-price elasticities have the expected negative sign, meaning that an increase in an input price results in a decrease of its own demand. Most of the subsituability-complementarity between the conventional inputs correspond to what has been found previously in the empirical cost literature. For instance, labor appears to be a complementary input to capital and energy and a substitute to materials in production. Material is a substitute to capital and energy inputs. Water is found to be substitute to capital, labor and energy as also observed by Dupont and Renzetti (2001). This result differs from Grebenstein and Field (1979) or Babin, Willis, and Allen (1982), where water was found to be a substitute to labor and a complement to capital.

The own-price elasticity of water demand is quite high, -1.085 at the sample mean. A similar result was obtained by Wang and Lall (1999) for the Chinese economy. However, since Wang and Lall (1999) adopts a marginal productivity approach, any comparison between elasticities should be made with caution. Our results are higher than those reported by Onjala (2001) for Kenya, who estimates water price elasticities ranging from -0.60 to 0.37. Once more, comparisons between elasticity estimates seem difficult to establish, since Onjala (2001) adopts a distinct approach based on a dynamic adjustment model without data on input prices and production levels. The water price elasticity estimate for Brazil (and for China) is significantly higher than the ones obtained for developed countries. This suggests that pricing policies can be a potential instrument for water conservation. But it is difficult to assess if this elasticity discrepancy between developing and developed countries has a structural-based explanation or can be solely attributed to the difficulty in getting accurate water-related data in developing countries. Indeed, the water price used in Wang and Lall (1999) corresponds to the marginal cost whereas Chinese water prices are far below this level. This may lead to an upward bias in their estimates. Moreover, both Brazilian and Chinese samples are composed by medium and large plants, which tend to have higher water price elasticities than small ones.[12]

Assessing the impact of Environmental Policy Instruments

The cost model can be used to assess how firms react to a modification of their regulatory environment. We consider the implementation of environmental policies: a water tax and a standard on effluent discharge.

Simulation method. First, given the observed input prices, outputs and technical characteristics of firms, we compute for each firm the estimated total cost and cost shares:

$$\widehat{TC}_i^o(Y_i^o, W_i^o; Z_i^o) \text{ and } \widehat{S}_{ij}^o(Y_i^o, W_i^o; Z_i^o). \tag{3}$$

Next, we consider an input price change (from W_{ij}^o to W_{ij}^1) or a change of output (from Y_i^o to Y_i^1) and we simulate the corresponding total cost and cost shares for each firm :

$$\widehat{TC}_i^1(Y_i^1, W_i^1; Z_i^o) \text{ and } \widehat{S}_{ij}^1(Y_i^1, W_i^1; Z_i^o). \tag{4}$$

Last, we compute the ratio of total cost and cost share change:

$$\Delta TC = \frac{\widehat{TC}_i^1 - \widehat{TC}_i^o}{\widehat{TC}_i^o} \text{ and } \Delta S_j = \frac{\widehat{S}_j^1 - \widehat{S}_j^o}{\widehat{S}_j^o} \tag{5}$$

which give the proportional change in cost and shares with respect to the initial situation. As we are especially interested in water use, we also report ΔX_{wat} which gives the proportional change in water derived demand.

Implementing water taxes: the Paraíba do Sul River Basin case. In Brazil, an important initiative for water management is the implementation of water charges promoted by the Paraíba do Sul River Basin Committee (CEIVAP). The charge is intended to apply to water users following four main principles. The charge mechanism must be based on measurable parameters, it must be socially acceptable, the water charges are supposed to act as signals about the economic value of water resources and last, the water tax must minimize economic impacts on users in terms of cost increases. The following simulations give some insights on the impact of a water tax on the cost of industrial firms.

In table 6, we simulate changes in production cost, input cost shares and water demand induced by different water price increases. As it can be seen, increases in water prices have a quite small impact on total costs. This should be expected, given the low water cost share. A 100% increase in water prices will result in less than a 0.5% increase in total costs. Moreover the water cost share variations will also be modest, falling by about 2.35%. The small impact of water price on total cost indicates that implementation of the Paraíba do Sul River Basin charge should not face strong resistance by industrial water users. At the same time, water consumption appears to be highly responsive to water prices. A 10% increase in water price induces a 9.33% reduction of water withdrawal.[13] These results suggest that given the low impact on total cost and the high responsiveness of water demand to price, water charges may be acceptable by firms and act as an effective instrument for water conservation.

Albeit its small impact on total cost, the water charge has a more substantial impact in terms of input mix. This is somewhat expected given the substitution possibilities between inputs. The most significant impact is observed for the energy share which, as already noted, has the highest substitution degree to water. Doubling the water price will result in a 8.21% increase in the energy cost share. One possible explanation is that firms facing higher water prices will use more water-saving processes (recirculation of water inside plants, reuse of wastewater for less quality demanding activities...) which are more energy intensive.

Production under more stringent environmental regulation. There is a vast literature (both theoretical an empirical) trying to assess the relationship between environmental regulation and productivity of firms. In a famous article published in 1991, Porter (1991) has suggested that implementing a more stringent environmental regulation may also lead to a decrease of costs and an increase of competitiveness of firms. But this so-called "Porter hypothesis" has been recognized by many economists as clearly controversial. Our cost estimates allow to simulate the impact of a more stringent environmental regulation on the cost structure of industrial firms.

Table 7 shows that reducing effluent discharge will result in significant changes in total cost and input mix. A 10% reduction of the effluent index will imply a 1.70% cost increase. If the effluent discharge index is reduced by half, this will imply a 11.24% increase in costs. This figure may be useful to support policy-maker assessment of environmental measures in term of cost-benefit analysis. Concerning input shares, the effluent discharge reduction will result in a decrease of the material cost share, while the share increases for all other inputs. This reflects the fact that effluent discharge is closely linked to materials use, as we have seen in the cost share estimates analysis. In order to decrease effluent discharges, firms should reduce materials use, while expending more on capital (by investing in pollution abatement technology), labor, energy and water. To achieve a 50% reduction in the effluent index, firms reduce by 10.94% the materials cost share. It should be noticed that the variation in the labor cost share is more significant than capital share adjustments. It seems that in adjusting to pollution environmental level targets, capital plays a relatively minor role compared to labor variations. One explanation of this result is that production technology of firms is considered as given: we do not allow firms to adapt to the more stringent environmental regulation by developing new technologies, maybe more capital-intensive. Adjustments described by our cost approach should be considered as short-term adjustments.

Toward a joint use of environmental norms and water tax? From table 7, it can be seen that the requirement to reduce the effluent index will lead to a substantial increase in water demand. For instance, a 20% decrease of the effluent index will induce a 12.80% increase in total water consumption. This relationship between effluent discharge and water demand indicates that, in order to attain the required levels of effluent reduction, firms use higher water volume for effluent dilution. It follows that policy makers face a tradeoff concerning environmental goals: water quality improvement measures will have a negative effect on water conservation.

A way to mitigate the negative impact of effluent norms on water conservation is to jointly implement a more stringent environmental norm together with an increase in water price (through a withdrawal tax, for instance). A 20% decrease of the effluent index together with a 12.5% increase of the water price will make the water withdrawals remain the same. This implies a 3.8% increase of the production cost, a figure slightly higher than in the scenario of more stringent environmental norms without water price increase (+3.6%). The water withdrawal reduction is made possible by increasing the cost share of energy (by 4.3% instead of 3.6% without water price change) and by reducing the cost share of material (by −3.7% instead of −3.5%) which is the most pollution-intensive input. One possible interpretation is that the reduction of water use requires to develop recirculation of water which is very energy-intensive. This substitution between energy and material is more visible when considering a 50% reduction of the index of effluent. Maintaining water use at the same level requires in such a case to increase the water price by 43.6%. The energy cost share increase is equal to 15.4% (versus 11.1% without water price change) whereas the fall in the material cost share represents −11.2% (versus −10.9% without water price change). The cost increases by 11.7% compared to the 11.2% increase without price change. The detrimental impact of a more stringent environmental norm on water conservation can be compensated, without a significant cost change, by a water price increase. This results clearly show that derived demands in production inputs are interdependent: Any policy aiming at modifying one input will affect the other ones and these interdependences must be internalized by the regulator.

V. CONCLUSION

In this paper we have investigated the water demand of Brazilian manufacturing plants with a special emphasis on the structure of cost and on pollution. We have characterized the structure of the industrial water demand by estimating a multiproduct translog cost function on a sample of 404 Brazilian firms located at São Paulo state observed in 1999.

We find that Brazilian firms exhibit a significant price elasticity, about -1.0 at the mean sample. This high value is similar to what has been found by other researchers working on developing countries (China for example). Moreover, our simulations suggest that implementing water charges will only have a limited impact on firm's cost. Given this low impact on costs and the high responsiveness of water demand to price, water charges may be both acceptable by firms and act as an effective instrument for water conservation. This finding provides support for the water tax currently being implemented in the Paraíba do Sul River Basin, Brazil.

Our simulations also provide some evidence on the strong relationship between effluent discharge and industrial water need. Policy makers should be careful when considering implementation of more stringent pollution standards. Reductions in effluent discharge may lead to a substantial increase in water demand. Hence, water managers face a tradeoff concerning environmental goals: water quality improvement policies may have a detrimental effect on water conservation. Interestingly, it is possible to mitigate the negative impact of a more stringent environmental norm by a joint use of effluent discharge norms and water charges. This reflects the idea that effluent norms and water charges should be viewed more as complementary tools than substitutes.

APPENDIX
Derivation of the Effluent Discharge Index

The derivation of the effluent discharge index can be decomposed into two stages. First, we perform a principal component analysis (PCA) on six variables concerning firms' water-related technical characteristics and environmental preferences. By this procedure we obtain an index reflecting best water-related environmental practices by firms. Then, we rescale this index and we obtain an index representing effluent discharges.

The PCA is a mathematical procedure that transforms a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables called principal components, each component being defined as a linear combination of the initial variables. The primary objective of this method is to summarize the data with little loss of information, and thus to provide a reduction in the dimensionality of the data. The interested reader may refer to Jolliffe (2002) for a complete presentation of the PCA method.

In our application, the PCA is based on the 6 following variables. First, q_w gives 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, $SUBENV$ gives firms's self-evaluation of environmental compliance status. $SUBENV$ takes values $\{1, 2, 3, 4, 5\}$ respectively if the firm always fails, regularly fails, periodically fails, just meets or exceeds the environmental requirements. $SUBENV$ should be negatively correlated with the water effluent index. Third, $ENVPREF$ describes firms's environmental preferences and is equal to $\{1, 2, 3\}$ respectively if environmental protection is not important, is important or is very important for the plant manager. $ENVPREF$ should be negatively correlated with the water effluent index. Fourth, $UNITENV2$ is equal to 1 if the industrial possesses an environmental unit. Fifth, $ISO14$ gives 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. $ISO14$ should be negatively correlated with the water effluent index. Last, $AUTOWAT$ is 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. Moreover, as shown on figure 1, the first axis is highly positively correlated with $UNITENV2$, $ENVPREF$, $ISO14$ and $AUTOWAT$. 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. In what follows, the effluent discharge index, Y_2, is 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.

[Figure 1, here]

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.

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Notes

[1]Frederick et al. (1997), in a survey for the US, report 494 estimates of the economic values of freshwater. Among these estimates, only 7 deal with industrial water use.

[2] Renzetti (1992) estimates the same model using an enlarged sample and finds similar results.

[3]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.

[4] 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.

[5]For instance, the World Bank has developed a model called *Industrial Pollution Projection System* (IPPS) that allows to estimate the level of pollution emissions per unit of industrial activity at the sectoral level, Hettige et al. (1994).

[6]ISO 14000 refers to a series of voluntary standards in the environmental field developed by the International Organization for Standardization located in Geneva, Switzerland.

[7]We have considered other specifications of the translog including for example cross-terms between environmental regulation variables, price of inputs and outputs. Most of these coefficients were not significant. For simplicity reasons and in order to limit the number of parameters to

be estimated, we only report the translog specification where environmental regulation variables only interact with input prices and outputs.

[8]The test statistics is equal to 78.5 whereas the critical value at 1% is 20.1.

[9]The test statistics is equal to 38.9 whereas the critical value at 1% is 24.7.

[10]Sectoral estimations are available upon request from the authors.

[11]We have tested the cost model with and without the regulation and environmental management variables D_{UNIT}, D_{INS3} and D_{SAN3} using a Wald test. The Wald statistics is equal to 40.04 whereas the critical value at 1% is $\chi^2(19) = 36.2$. We reject the null hypothesis of no effect of regulation and environmental management variables on cost. These variables have a significant impact on cost, although limited.

[12]Since large firms withdraw high volumes of water, they face high incentives to invest in water-recycling activities. Water recirculation being a substitute to water withdrawal, these firms should have a more elastic water demand.

[13]This figure is compatible with the estimated price elasticity of water demand, -1.08 on average.

TABLE 1
Descriptive Statistics on Costs

Variable	Unit	Mean	Std. Dev.	Min.	Max.
TC	R$	17,226,823	32,408,331	100,000	289,800,000
Y_1	index	117.119	230.587	2.092	2,146.769
Y_2	index	4.822	1.402	1.000	7.738
S_k	–	0.200	0.125	0.005	0.875
S_l	–	0.297	0.150	0.037	0.917
S_e	–	0.039	0.037	0.000	0.255
S_m	–	0.457	0.170	0.010	0.954
S_w	–	0.006	0.012	0.000	0.150
W_k	R$ by 1,000 R$	9.983	7.877	148	213
W_l	R$ by employee	14,394	7,984	3,111	47,806
W_e	R$ by 1,000,000 Kcal	6.946	0.902	4.071	8.107
W_m	R$ by unit of material index	8.624	5.723	24.402	63.786
W_w	R$ by m^3	3.675	1.954	0.004	9.709
X_k	Index	25,573	66,189	12	954,894
X_l	Number of employees	271	475	6	4,861
X_e	1,000,000 Kcal	94,882	210,450	10	2,261,891
X_m	Index	307,758	641,218	167	5,917,206
X_w	m^3	51,438	176,737	6	1,560,000

TABLE 2

DESCRIPTIVE STATISTICS FOR REGULATION AND TECHNICAL CHARACTERISTICS

Variable		Frequency	Percent
D_{SAN3}	Yes	15	3.71
	No	389	96.29
D_{INS3}	Yes	212	52.48
	No	192	47.52
D_{UNIT}	Yes	73	18.07
	No	331	81.93
$IBGE6$	Chemical	40	9.90
	Electricity	57	14.11
	Food	18	4.46
	Metals	68	16.83
	Other	140	34.65
	Textiles	81	20.05

D_{SAN3} is a dummy for sanctioned firms.
D_{INS3} is a dummy for regularly inspected firms.
D_{UNIT} is a dummy for the presence of an environmental unit.
$IBGE6$ are dummies for industrial sectors.

TABLE 3

PARAMETER ESTIMATES OF THE TRANSLOG COST FUNCTION

Variable	Est.	St.Err	St.-T	Variable	Estimate	St.Err	St.-T
$CONST$	15.551	0.091	170.536	Y_1D_{UNIT}	0.035	0.047	0.753
Y_1	0.852	0.058	14.820	Y_2D_{UNIT}	0.151	0.177	0.850
Y_2	−0.335	0.218	−1.537	W_KD_{INS3}	0.007	0.012	0.607
W_K	0.198	0.017	11.603	W_LD_{INS3}	0.218	0.056	3.875
W_L	0.321	0.023	13.854	W_ED_{INS3}	−0.001	0.005	−0.300
W_E	0.048	0.007	7.044	W_MD_{INS3}	−0.005	0.015	−0.297
W_M	0.422	0.023	18.552	W_WD_{INS3}	0.003	0.003	0.901
W_W	0.011	0.005	2.209	W_KD_{SAN3}	−0.028	0.012	−2.371
W_KW_K	0.052	0.118	0.445	W_LD_{SAN3}	−0.105	0.057	−1.859
W_KW_L	−0.317	0.110	−2.880	W_ED_{SAN3}	0.003	0.005	0.579
W_KW_E	0.012	0.041	0.301	W_MD_{SAN3}	0.008	0.016	0.528
W_KW_M	0.252	0.085	2.950	W_WD_{SAN3}	0.001	0.004	0.341
W_KW_W	0.000	0.006	−0.011	W_KD_{UNIT}	0.021	0.014	1.508
W_LW_L	0.176	0.091	1.942	W_LD_{UNIT}	−0.113	0.043	−2.627
W_LW_E	−0.035	0.063	−0.552	W_ED_{UNIT}	−0.001	0.006	−0.243
W_LW_M	0.175	0.108	1.617	W_MD_{UNIT}	−0.004	0.019	−0.202
W_LW_W	0.000	0.008	0.040	W_WD_{UNIT}	−0.004	0.004	−1.037
W_EW_E	−0.099	0.030	−3.324	$D_{MET}W_K$	−0.009	0.020	−0.454
W_EW_M	0.117	0.036	3.222	$D_{MET}W_L$	−0.004	0.027	−0.166
W_EW_W	0.004	0.002	1.825	$D_{MET}W_E$	0.015	0.009	1.688
W_MW_M	−0.540	0.133	−4.068	$D_{MET}W_M$	0.000	0.026	−0.018
W_MW_W	−0.004	0.007	−0.526	$D_{MET}W_W$	−0.001	0.006	−0.141
W_WW_W	−0.001	0.002	−0.348	$D_{CHEM}W_K$	−0.084	0.031	−2.748
Y_1Y_1	−0.010	0.020	−0.538	$D_{CHEM}W_L$	−0.071	0.042	−1.689
W_KY_1	0.015	0.006	2.414	$D_{CHEM}W_E$	−0.051	0.014	−3.551
W_LY_1	−0.060	0.008	−7.214	$D_{CHEM}W_M$	0.203	0.039	5.253
W_EY_1	−0.001	0.002	−0.336	$D_{CHEM}W_W$	0.003	0.007	0.493
W_MY_1	0.048	0.008	6.003	$D_{FOOD}W_K$	−0.227	0.066	−3.447
W_WY_1	−0.002	0.002	−1.074	$D_{FOOD}W_L$	−0.205	0.085	−2.396
Y_2Y_2	−0.027	0.280	−0.097	$D_{FOOD}W_E$	−0.103	0.028	−3.742
W_KY_2	−0.013	0.021	−0.636	$D_{FOOD}W_M$	0.544	0.096	5.655
W_LY_2	−0.046	0.029	−1.581	$D_{FOOD}W_W$	−0.009	0.011	−0.891
W_EY_2	−0.006	0.008	−0.686	$D_{TEX}W_K$	−0.019	0.019	−1.029
W_MY_2	0.071	0.028	2.559	$D_{TEX}W_L$	−0.020	0.025	−0.808
W_WY_2	−0.006	0.006	−1.016	$D_{TEX}W_E$	−0.001	0.007	−0.087
Y_1Y_2	−0.047	0.052	−0.908	$D_{TEX}W_M$	0.043	0.025	1.723
D_{UNIT}	0.175	0.073	2.396	$D_{TEX}W_W$	−0.002	0.005	−0.446
D_{INS3}	0.049	0.041	1.197	$D_{ELEC}W_K$	0.048	0.020	2.348
D_{SAN3}	−0.034	0.044	−0.765	$D_{ELEC}W_L$	0.017	0.027	0.642
Y_1D_{INS3}	0.025	0.037	0.656	$D_{ELEC}W_E$	0.003	0.008	0.353
Y_2D_{INS3}	0.023	0.137	0.168	$D_{ELEC}W_M$	−0.071	0.027	−2.634
Y_1D_{SAN3}	0.042	0.040	1.067	$D_{ELEC}W_W$	0.002	0.006	0.378
Y_2D_{SAN3}	−0.039	0.135	−0.287				

$\bar{R}^2$: 0.906.

TABLE 4
PARAMETER ESTIMATES OF THE COST SHARES

	Capital		Labor		Energy		Material		Water	
Variable	Est.	St-T	Est.	St-T	Est.	St-T	Est.	St-T	Est.	St-T
$CONST$	0.198	11.599	0.321	13.854	0.048	7.040	0.422	18.552	0.011	2.209
Y_1	0.015	2.414	−0.060	−7.214	−0.001	−0.336	0.048	6.003	−0.002	−1.074
Y_2	−0.013	−0.636	−0.046	−1.581	−0.006	−0.686	0.071	2.559	−0.006	−1.016
W_K	0.052	0.443	−0.317	−2.880	0.012	0.300	0.252	2.944	0.000	−0.011
W_L	−0.038	−3.080	0.176	1.942	−0.004	−0.899	−0.035	−2.124	0.000	−0.073
W_E	0.012	0.300	−0.035	−0.552	−0.099	−3.319	0.117	3.222	0.004	1.825
W_M	0.252	2.944	0.175	1.617	0.117	3.222	−0.540	−4.068	−0.004	−0.526
W_W	0.000	−0.011	0.000	0.040	0.004	1.825	−0.004	−0.526	−0.001	−0.348
D_{UNIT}	0.021	1.508	−0.113	−2.627	−0.001	−0.243	−0.004	−0.202	−0.004	−1.037
D_{INS3}	0.007	0.607	0.218	3.875	−0.001	−0.300	−0.005	−0.297	0.003	0.901
D_{SAN3}	−0.028	−2.371	−0.105	−1.859	0.003	0.579	0.008	0.528	0.001	0.341
D_{MET}	−0.009	−0.453	−0.004	−0.166	0.015	1.687	0.000	−0.018	−0.001	−0.141
D_{ELEC}	0.048	2.347	0.017	0.642	0.003	0.353	−0.071	−2.634	0.002	0.378
D_{CHEM}	−0.084	−2.747	−0.071	−1.689	−0.051	−3.551	0.203	5.253	0.003	0.493
D_{TEX}	−0.019	−1.028	−0.020	−0.808	−0.001	−0.087	0.043	1.723	−0.002	−0.446
D_{FOOD}	−0.227	−3.434	−0.205	−2.396	−0.103	−3.742	0.544	5.655	−0.009	−0.891
	$\bar{R}^2$: 0.222		$\bar{R}^2$: 0.233		$\bar{R}^2$: 0.217		$\bar{R}^2$: 0.290		$\bar{R}^2$: 0.198	

TABLE 5

CROSS AND OWN PRICE ELASTICITY OF INPUT DEMANDS, (ϵ_{jk})

	Capital	Labor	Energy	Material	Water
Capital	-0.539	-1.283	0.1	1.715	0.006
	(0.587)	(0.549)	(0.202)	(0.427)	(0.028)
Labor	-0.866	-0.11	-0.077	1.046	0.007
	(0.37)	(0.306)	(0.211)	(0.364)	(0.026)
Energy	0.511	-0.581	-3.468	3.425	0.113
	(1.03)	(1.589)	(0.754)	(0.921)	(0.059)
Material	0.752	0.679	0.295	-1.724	-0.002
	(0.187)	(0.236)	(0.079)	(0.29)	(0.016)
Water	0.191	0.348	0.721	-0.174	-1.085
	(0.922)	(1.271)	(0.373)	(1.199)	(0.263)

Elasticities computed at the mean sample. Standard-errors in parentheses computed according Binswanger (1974), considering the cost as non-stochastic.

TABLE 6

Impact of a Price Increase on Cost and Input Use

W_W	+10%	+20%	+50%	+100%	+200%
$\Delta\, TC$	0.064%	0.120%	0.263%	0.443%	0.690%
$\Delta\, S_K$	−0.003%	−0.006%	−0.013%	−0.022%	−0.035%
$\Delta\, S_L$	0.011%	0.021%	0.048%	0.082%	0.129%
$\Delta\, S_E$	1.129%	2.159%	4.801%	8.208%	13.009%
$\Delta\, S_M$	−0.083%	−0.158%	−0.351%	−0.600%	−0.952%
$\Delta\, S_W$	−0.323%	−0.617%	−1.372%	−2.346%	−3.718%
$\Delta\, X_{wat}$	−9.327%	−17.082%	−34.079%	−50.966%	−67.700%

Note: Percentage computed at the mean sample.

TABLE 7

IMPACT OF A REDUCTION OF THE EFFLUENT INDEX ON COST AND INPUT USE

Y_2	-1%	-10%	-20%	-30%	-50%
$\Delta\, TC$	0.163%	1.697%	3.598%	5.761%	11.234%
$\Delta\, S_K$	0.072%	0.752%	1.593%	2.546%	4.948%
$\Delta\, S_L$	0.172%	1.799%	3.811%	6.091%	11.838%
$\Delta\, S_E$	0.161%	1.687%	3.574%	5.712%	11.100%
$\Delta\, S_M$	−0.159%	−1.662%	−3.520%	−5.627%	−10.935%
$\Delta\, S_W$	0.384%	4.024%	8.522%	13.622%	26.473%
$\Delta\, X_{wat}$	0.548%	5.870%	12.796%	21.125%	44.426%

Note: Percentage computed at the mean sample.

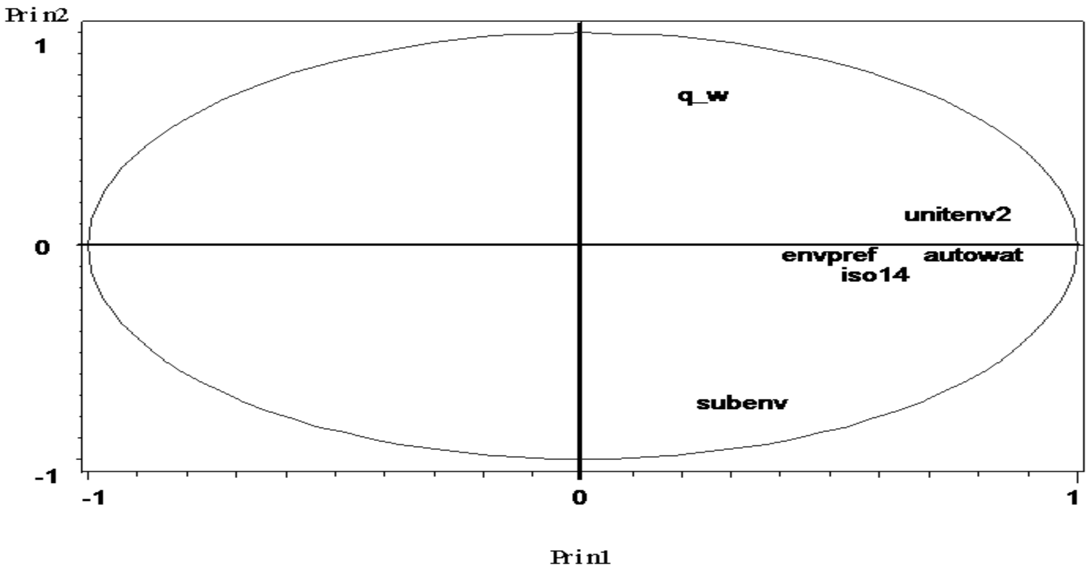

FIGURE 1
Representation of Variables in the Space of the Two First Principal Components