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AN EMPIRICAL ANALYSIS OF THE NONLINEAR RELATIONSHIP BETWEEN ENVIRONMENTAL REGULATION AND MANUFACTURING PRODUCTIVITY

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The relationship between environmental regulation and productivity has been broadly analyzed. Here, we propose the use of one member of the family of exponential Gumbel distributions in order to study a potential nonlinear relationship between environmental regulation and manufacturing productivity in Mexico using a data set at the plant level. We show that the link between environmental regulation and productivity is in fact nonlinear and that there is a decreasing trade-off between those variables in the manufacturing industry. We find that such trade-off is high for small firms, but almost negligible for large companies. Thus, we argue that much of the debate on different effects is due to the heterogeneity of the industry. This result might be useful for the design of policies devoted to enhancing environmental performance.

JEL classification codes: C46, C51, D24, Q52

Key words: exponential Gumbel distribution, Porter Hypothesis, nonlinear relationships, Mexico's manufacturing industry, environmental performance

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I. Introduction

The relationship between environmental regulation and productivity is controversial. Although several studies have dealt with this issue since the late 70s, the academic debate has been centered on explaining the so-called Porter Hypothesis (Porter and van der Linde 1995) since the 90s. The Porter Hypothesis (PH) sustains that there is a positive relationship between environmental regulation and firms´ productivity. However, this conclusion has been severely questioned by economists as it challenges the paradigm of profit maximization on which corporate rationality is based. So, a controversy exists among economists, who have found that environmental regulations tend to reduce firms' productivity, and business strategists, who sustain that environmental regulations enhance productivity (reviews on the subject have been presented by Jaffe et al. 1995; Wagner 2003; Ambec and Barla 2006; Brannlund and Lundgren 2009; among others).

This debate has given rise to abundant empirical studies regarding the direction and magnitude of such relationship. In fact, the review by Brannlund and Lundgren (2009) points out that empirical research concerning the PH has dealt with three main effects of environmental regulations: on research and development, on financial impacts, and on efficiency and productivity. For the first two categories, there is no statistically conclusive evidence supporting the PH. In contrast, the latter approach has found statistically significant but mixed results, maybe in part due to the larger number of studies performed on the subject since the late 1970s. Early works (Barbera and McConnell 1986; Crandall 1981; Denison 1979; Gray 1987; Haveman and Christainsen 1981; Norsworthy, Harper and Kunze 1979), based on aggregate data, show that environmental regulations account for a slow-down in productivity growth in the US. In a recent literature survey, Lanoie et al. (2007), conclude that the contemporaneous direct effect of environmental policy stringency on business performance is negative and that innovation does not offset the costs of complying with regulations.

On the other hand, there is also evidence that environmental regulations might be favorable for firms' productivity. For instance, Berman and Bui (2001) show that refineries in the Los Angeles area have higher productivity levels than other US refineries despite the more stringent regulation in this area. Alpay, Buccola and Kerkvliet (2002) find that more stringent regulations seem to increase the productivity of the Mexican food processing industry. Isaksson (2005) examined the impact of regulation on costs functions of 114 combustion firms, finding that

extensive emission reductions have taken place at zero cost. Darnall, Henriques and Sadorsky (2007) proved that better environmental performance enhances business performance, but that a stricter environmental regulation has a negative impact. Obviously, the debate on this issue is not closed (e.g., Brannlund and Lundgren 2009; Ambec et al. 2010) and, given the important policy implications, further research is thus needed on a number of aspects including new forms of modeling relationships between environmental regulation and business performance (Wagner 2003).

Hence, in this paper, we propose a new empirical approach to face this dilemma. Specifically, we apply a nonlinear regression model in order to study the nature of the PH. Given that environmental regulation and productivity variables are often skewed to the right (asymmetric distributions), and that we hypothesize that the relationship between them is nonlinear, it can be well represented by one member of the family of exponential Gumbel distributions, and its associated regression model (Gumbel 1960), which is nonlinear and heteroskedastic. This conditional nonlinear regression model implies changing marginal effects of the explanatory variable over the entire distribution of the dependent variable. In fact, it allows us to estimate different marginal effects of regulation (i.e., pollution abatement expenditures) at different points in the conditional productivity distribution.[1] To the best of our knowledge, this specific Gumbel regression model has not been previously used in the field of economics, although it is worth mentioning that other members of the Gumbel family have been often used in microeconomics, finance and risk management.

Thus, the objective of this study is twofold. First, we propose the use of the exponential Gumbel distribution and its associated regression curves to assess potential nonlinear relationships. Second, we apply this tool to investigate the effect of environmental regulation on productivity at the firm level in Mexico. In other words, we aim with the implementation and application of the Gumbel exponential regression model to contribute to elucidate the controversial arguments raised by the PH.

[1] It is worth mentioning that nonlinearities are often captured by using higher order terms of the explanatory variables in the context of the linear regression model, instead of this type of Gumbel regression model. Another valid approach could be to linearize the variables by using logs, and estimating a linear regression model assuming a log-normal distribution.

II. Methods

A. Dataset

We use data from the 2002 national industrial survey in Mexico (INEGI 2003). The Mexican statistics agency (INEGI) started to collect industrial data on a regular basis since 1994. In 2003 the survey methodology changed and consequently data are not comparable with former samples. This database is fully described in Dominguez and Brown-Grossman (2007). It is sample of about 6,000 firms, covering 205 industrial categories. We use here the 2002 database, which includes information on 1,738 firms.[2] From this total, 903 observations have complete data to perform our analysis. Such firms represent about 65% of the total gross aggregated value of the INEGI census in 2002. We performed several steps. First, to ensure the representativeness of the 2002 data we use, we checked out distributions equality, between the whole sample (universe) and the used sample, with a Kolmogorov-Smirnov test. The p-value we obtained for such test (0.65) means that we are not able to reject the null hypothesis of equality of both distributions (i.e. universe and sample) for all the relevant variables.

Table 1. Industry's structure per sector

	Number of establishments
Food, beverage, and tobacco	78
Textiles, garments, and leather	114
Wood and wood products	26
Paper, print, and publishing	77
Chemicals, rubber, and plastic	290
Nonmetallic minerals, other than petroleum derivatives	35
Basic metals industries	45
Metal products, machinery, and equipment	227
Other manufacturing industries	11
Total	903

Source: 2002 annual industry survey, INEGI, Mexico.

[2] Here we are working with a cross-section, however, we are currently working on the development of the Gumbel model for panel data.

Second, we constructed a plant's pollution abatement expenditures per employee indicator (the sum of investment on machinery and equipment aimed at reducing pollution at the plant level) and a labor productivity indicator (output per employee).[3] Table 1 shows the industry's structure per sector. Unfortunately the survey does not break down the pollution abatement measure into its components, thus, a disaggregated analysis, by type of abatement components, could not be carried out in this paper (Dominguez and Brown-Grossman 2007).

We constructed other variables to be used as controls such as: industry fixed effects, size of the plants, interactions between size and pollution expenditure, levels of energy use and a foreign investment indicator, among others (INEGI 2003). Table 2 reports descriptive statistics of the levels of the variables.

Table 2. Descriptive statistics

	Mean	Standard deviation	Min	Max	Skewness	Kurtosis
*Pollution abatement expenditures**	5.75	18.15	0.001	275.03	7.71	84.87
Productivity (output per employee)	42.23	59.54	0.087	568.37	3.85	23.01
*Firm size***	3.19	1.19	1	5	0.137	2.2
Energy intensity (high energy user=1, low=0)	0.09	0.32	0	1	2.8	9.11
Foreign (foreign firm=1, domestic=0)	0.11	0.31	0	1	2.46	7.06

Note: *Thousands of 1993 pesos per employee. ** Dummy variable indicating firm size: (1) very small (2) small (3) medium (4) large (5) very large. Source: Annual industrial survey (EIA), INEGI, Mexico. (903 plants)

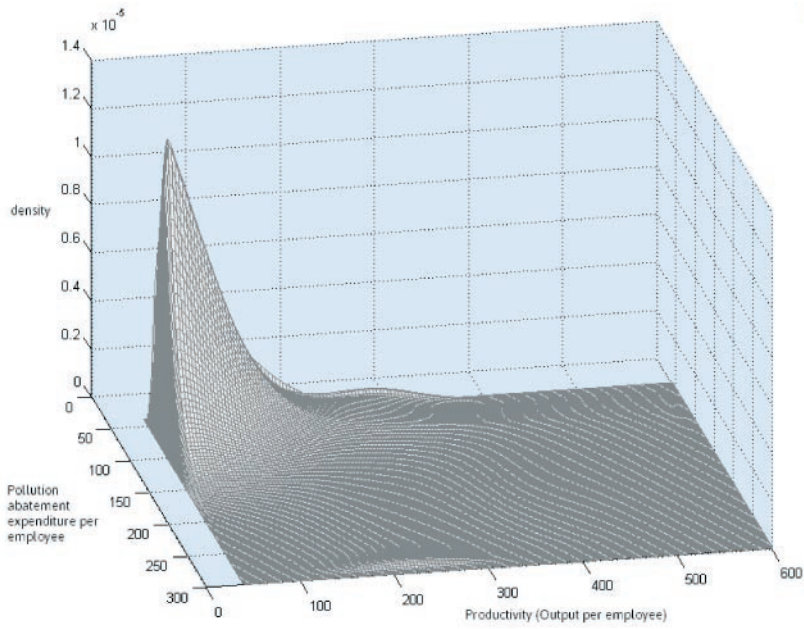
Third, we used a set of graphical techniques since, in selecting a suitable model we take into account not only theoretical issues, but also all the statistical systematic information in the data (Spanos 1986). Such analysis revealed that the dataset contains a number of outliers, suggesting that the variables were highly

[3] The pollution abatement variable can only be considered as a proxy for the effort made by firms to improving their environmental performance.

skewed (with asymmetric distributions) and leptokurtic. Figure 1 shows the bivariate Kernel estimate of productivity and pollution abatement per employee density function, confirming that the data are highly asymmetric (skewed to the right), and suggesting that the hypothetical regression function has a nonlinear nature.

Hence, following Silverman (1998), given that the univariate empirical distributions (Kernel density estimates) of such variables are similar and highly skewed to the right, we hypothesize that an exponential Gumbel distributive assumption might be a reasonable statistical assumption in specifying a conditional model of manufacturing productivity in Mexico.

Figure 1. Bivariate density estimate of productivity and pollution abatement expenditures



B. Model specification

In accordance with the previous section, we propose the hypothesis that a good conditional model for nonlinear relationships, like the one between environmental regulation and productivity, is provided by the exponential Gumbel regression model (Gumbel 1960). This specific conditional model can be derived from the following bivariate exponential Gumbel density:[4]

$$f(y,x) = \left[(1+\delta \cdot y) \cdot (1+\delta \cdot x) - \delta \right]^{\{-y-x-\delta \cdot y \cdot x\}}, \tag{1}$$

where x is a measure of environmental regulation, y is manufacturing productivity indicator, and δ is a parameter that shapes the density function.

The exponential Gumbel regression model is nonlinear and has a heteroskedastic specification (Gumbel 1960; Kotz, Balakrishnan and Johnson 2000; Wooldrige 2002):

$$y_i = \frac{1+\delta+\delta x_i}{(1+\delta x_i)^2} + e_i, \quad e_i \sim Gumbel\ IID(0, \omega_i^2), \tag{2}$$

where δ is the parameter that describes the probabilistic association between y and x, and, ω_i^2 is the conditional variance that takes the form:

$$\omega^2{}_i = \frac{(1+\delta+\delta x_i)^2 - 2\delta^2}{(1+\delta x_i)^4}, \tag{3}$$

The marginal effects can be represented by:

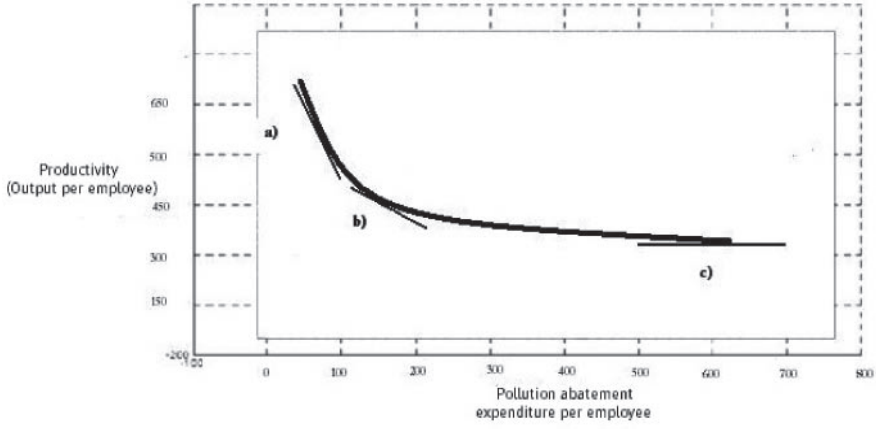
[4] We agree with an anonymous referee that adding a variable such as capital stock per employee would help reduce estimation biases. However, this would imply a trivariate model instead of a bivariate model, which would be beyond the main objective of this paper. In fact, a Gumbel bivariate model has not been previously proposed and therefore a trivariate or even a quatri-variate model would be a nice extension of our work. Here, we have the aim of presenting an innovative way for estimating nonlinear relationships and thus, we instead stayed with the bivariate Gumbel model for, hopefully, paving the way for further refinements. Finally, it is worth mentioning that this distribution is one member of the exponential family developed by Gumbel and that there are other possible regression models for different exponential distributions.

$$\frac{dE(y_i / x_i)}{dx_i} = -\frac{\delta(1+\delta+\delta x_i)}{(1+\delta x_i)^3} \quad , \tag{4}$$

The negative marginal effect in (4) is decreasing and it depends on the values of the independent variable.

Figure 2 shows the probability contour plot with a potential regression curve as the one proposed. It suggests that a good description of the relationship between productivity and regulation (as measured by plant's pollution abatement expenditures) might be provided by a bivariate Gumbel, nonlinear, heteroskedastic model. The economic meaning of a negative nonlinear relationship is twofold: first, there might be a decreasing trade-off between productivity and environmental regulation at the manufacturing industry in Mexico; and, second, the average value of productivity might change at a non constant rate as pollution abatement costs per employee change (i.e., there may be changing partial effects, associated to the different levels of pollution control spending).[5]

Figure 2. Gumbel regression curve (productivity and pollution abatement expenditures data).



[5] Note that the hypothetical function in Figure 2 corresponds approximately to the shape depicted in Figure 1 using the data.

III. Results and discussion

As we were interested in responding how the average value of productivity changes as environmental regulation becomes stricter (as the level of pollution abatement expenditures per employee increase), we estimated equation (2) using a maximum likelihood method, and controlling for some other important features of the firm, such as the origin of the plant (foreign or local), the level of energy use, the size of the plant, interactions of size and pollution abatement expenditures, and the industry sector. The estimated model and misspecification tests are reported in Tables 3 and 4 respectively.

Table 3. Bivariate exponential Gumbel regression model (productivity and pollution abatement expenditure per employee)

Parameter	Coefficient
δ	0.53
Correlation Coefficient (ρ)	-0.3
Additional control variables	
*Interaction term (pollution abatement expenditure * firm size)*	0.1212767 (0.0110925)
Foreign firm	42.84256 (2.72073)
Energy intensity	6.408539 (4.303483)
Industry type 1(Food, beverage, and tobacco)	36.76553 (2.927894)
Industry type 6 (Nonmetallic minerals, other than petroleum derivatives)	24.80149 (5.264434)
Number of observations	903

Note: Controls are dummy variables which take values of one if the company is a foreign one, is based on energy intensive process and has big technological capabilities. Other regressors were excluded based on F tests. Standard error in parenthesis.

Table 4. Misspecifications tests for the exponential Gumbel regression model

Misspecifications tests	F-test	P-value
Additional nonlinearity in mean (A1)	3.82	0.0509
Trend in conditional mean (A2)	7.56	0.1000
Mean well-specified: *alpha=1*	14.66	0.0110
Mean well-specified: gamma=1	75.34	0.0675

Note: Misspecifications tests are explained in detail in Appendix A.

The results show that the parameter of interest (δ) is positive (0.53), but this estimate, in the Gumbel regression model, implies a negative correlation between productivity and environmental regulation of around -0.3. A negative sign suggests the existence of a trade-off between such variables. Table 4 shows the results of a set of misspecification tests for the model, which confirm that our model is statistically adequate, since no departures from the underlying assumptions of the Gumbel model exist (Spanos 2006).

We also find that the magnitude of the relationship between environmental regulation and manufacturing productivity differs among groups of firms. More precisely, its magnitude depends on the place occupied by firms in the productivity distribution. It is likely that firm's level of pollution control spending and size affects the impact that regulation has on firm´s productivity. The differences might be due to economies of scale, where larger firms are more able to bear environmental regulations costs than smaller firms. This finding can be related to Figure 2, where we have added three tangents in order to explain that: (a) smallest firms (with low levels of pollution abatement spending) face a very steep negative slope; (b) medium-size firms face a less pronounced slope; and (c) larger firms (with high levels of spending) face a slope close to zero.

Moreover, the relevant estimates to further assess the differences in magnitude among marginal effects of regulation on productivity come from equation (4). Given that the Gumbel regression model is not linear, we can estimate different marginal effects of environmental regulation at different points in the conditional distribution of productivity. Specifically, we can compute the different marginal effects of regulation evaluated at the mean of the distribution for the 10th, 30th, 50th, 90th and 95th percentiles. The results are shown in Table 5.

Table 5. Marginal effects of regulation on productivity at the firm level in Mexico

	10%	30%	50%	90%	95%
Quantile regression	-0.1080	-0.9530	-0.2650	-0.4533	-0.4536
OLS (log levels)	-1.0939	-0.0982	-0.0383	-0.0053	-0.0027
Exponential Gumbel	-0.7901	-0.7002	-0.2688	-0.1863	-0.0043

The last row of Table 5 shows the heterogeneous responses (changing marginal effects) of productivity, by percentiles, to regulation (pollution abatement expenditures) according to the exponential Gumbel regression. The quantile and OLS logarithmic estimates are also shown for comparison purposes in rows one and two of the same table. The diminishing Gumbel marginal effects, from left to right, mean that a unit increase in pollution abatement expenditures per employee will bring a reduction of 0.79 of a unit of output per employee for those companies located in the 10th percentile, which interestingly enough are the smallest firms. In contrast, an increase in one peso in pollution abatement for firms located in the 95th percentile, which are the largest firms, will only reduce output by a negligible amount of about 0.0043 of a unit. Thus, the cost of regulation is lower, in terms of productivity, for the plants located in the upper percentiles (the larger ones), while smaller plants face the higher costs of regulation. In conclusion, there exists an heterogeneous and decreasing trade-off between environmental regulation and productivity in the Mexican manufacturing industry. The interesting fact to note here is that the inverse relationship between productivity and pollution abatement spending along the productivity distribution holds, no matter the type of model used, which confirms the robustness of the direction of such relationship.

Our Gumbel model empirical results are relevant given that having a precise estimate of the marginal effects is extremely important for policy purposes. For example, if environmental subsidies are recommended for helping smaller firms to comply with pollution abatement regulations, the number of firms supported would drastically vary, depending on the model used (Gumbel, Quantile or log-log). That is, if estimations were done with a logarithmic regression, only about 10% of the smaller firms would be supported, since the marginal effects are negligible for the rest of the distribution, while this figure would be up to 90% with an exponential Gumbel estimation. The previous result is confirmed by the estimation of the Gumbel regression model. Since we have included interactions between plant size and pollution abatement expenditures in order to capture size effects, and we have empirical evidence of a positive correlation between plant size and

pollution abatement expenditures in Mexico (see Dominguez 2006; Dominguez and Brown-Grossman 2007), we can infer that the negative effect of regulation on productivity, in Mexico´s case, is larger for small firms but almost negligible for larger companies. This outcome implies that the PH effect depends on a number of factors, among which not only market structure is involved (Greaker 2006) but also plant size.

IV. Concluding remarks

We propose in this paper an exponential regression model discussed by Gumbel in a seminal paper in 1960 as an appropriate model to capture potential nonlinear relationships in the field of economics, in the presence of highly skewed and non-normal data. Specifically, we propose the use of a regression function associated to a distribution with exponential Gumbel margins, whose regression curves are not straight lines and do not intersect at the common mean. We postulate that this approach is useful for studying nonlinear phenomena, such as the relationship between environmental regulation and manufacturing productivity in Mexico. Thus, we apply the exponential Gumbel regression model to investigate the link between regulation and productivity at the plant level in Mexico, examining the effect of environmental regulation, as measured by pollution abatement expenditures per employee, on manufacturing productivity among a set of Mexican industries.

Our empirical results show that the link between environmental regulation and productivity is in fact nonlinear and the proposed model provides a robust way to describe it. We find that there exists a decreasing trade-off between productivity and environmental regulation in the manufacturing industry in Mexico. We also find that such trade off is more important for small firms and almost negligible for large companies, given that there is empirical evidence of a positive correlation between plant size and pollution abatement expenditures in Mexico.

According to the Porter hypothesis, there is a positive relationship between regulation and economic performance.. Here, we show that the relationship is negative and it depends on firm size. Hence, we argue that such heterogeneity reflects the diverse findings, for and against the Porter hypothesis. Strict positive relationships might be found when controlling for other effects, presumably among larger producers. This remains, however, as an open question which deserves further research.

Our empirical results might be useful for the design of national programs to enhance environmental performance, given that knowledge of the magnitude of firms' productivity effects could help to optimize the burden sharing of pollution control costs among firms.

Appendix

The misspecification tests applied to the exponential regression model are based on the F-type tests that follow.

A. Additional nonlinearity in the conditional mean

To test for the presence of additional nonlinearities in the conditional mean we can test if $\alpha_2 = 0$ in the following regression:

$$y_i = \alpha_0 + \alpha_1 \hat{y}_i + \alpha_2 \hat{y}_i^2 + u_i \quad , \tag{A1}$$

where $\hat{y}_i$ are the Gumbel model fitted values. Furthermore, we can also expect that $\alpha_1 = 1$ if the pre-specified model is the correct one.

B. Trend in conditional mean

To test for the presence of additional nonlinearities, like a linear trend in the conditional mean, we can test if $\gamma_2 = 0$ in the following regression:

$$y_i = \gamma_0 + \gamma_1 \hat{y}_i + \gamma_2 t + u_i \ , \tag{A2}$$

where $\hat{y}_i$ are the Gumbel model fitted values. Furthermore, we can also expect that $\gamma_1 = 1$ if the pre-specified model is the correct one.

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