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Relationship between technological progress, capital elasticity and emissions of industrial pollutants for the production sectors in Catalonia

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Abstract

As is known, the Kyoto Protocol proposes to reinforce national policies for emission reduction and, furthermore, to cooperate with other contracting parties. In this context, it would be necessary to assess these emissions, both in general and specifically, by pollutants and/or among productive sectors. The object of this paper is precisely to estimate the polluting emissions of industrial origin in Catalonia in the year 2001, in a multivariate context which explicitly allows a distinction to be made between the polluter and/or the productive sector causing this emission.

Six pollutants considered, four directly related to greenhouse effect. A multi-level model, with two levels, pollutants and productive sectors, was specified. Both technological progress and elasticity of capital were introduced as random effects. Hence, it has been permitted that these coefficients vary according to one or other level. The most important finding in this paper is that elasticity of capital has been estimated as very non-elastic, with a range which varies between 0.162 (the paper industry) and 0.556 (commerce). In fact, and generally speaking, the greater capital the sector has, the less elasticity of capital has been estimated.

Key words: Kyoto protocol, multilevel model, technological progress

1. Introduction

In recent years societies have been consuming natural resources inappropriately, provoking serious environmental problems. At this moment in time, as we know, the main problem is climate change. Human activity, mainly due to the burning of fossil fuels, is producing artificial emissions which add carbon dioxide to the atmosphere. Thus, the "greenhouse effect", which is actually a natural phenomenon caused by several gases present in the atmosphere and is responsible for the temperatures which makes Earth inhabitable, has escalated, producing to a greater or lesser degree, global warming. On the one hand, climate change is one of the main existing threats for sustainable development, and on the other, it represents one of the main environmental challenges affecting global economy, health and social welfare.

In 1997, during the United Nations Framework Convention on Climate Change, in the Japanese city of Kyoto, the 'Kyoto Protocol' was signed. It entails an agreement in which industrialized countries and transition economies agree to reduce their collective emissions by 5.2% in six greenhouse gases of human origin, including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), as well as three industrial gases, hydrofluorocarbons (HFC), perfluorocarbons (PFC_S) and sulphur hexafluoride (SF_6). This reduction should take place between 2008 and 2012, taking the 1990 levels as a reference base.

The European Union has had to reduce the aforementioned emissions by 8%[1]. In the case of Spain, it was agreed not to increase greenhouse gas emissions in the 2008-2012 period beyond 15%. In Catalonia, in accordance with the Catalan Convention for Climatic Change, a reduction of 5.33 million tons of greenhouse gas emissions has been planned for the 2008-2012 period (Department of the Environment and Housing, 2008).

[1] The commitments undertaken by each Member State vary according to a series of reference parameters.

In order to reach these goals, the Protocol proposes, on the one hand, to reinforce or establish national policies for emission reduction (increase in energy efficiency, promotion of sustainable agricultural methods, development of renewable energy sources, etc) and, on the other hand, to cooperate with other contracting parties (exchange of experiences or information, coordination of national policies with a view to greater efficiency through cooperation mechanisms, such as the emission license, joint application mechanisms and the clean development mechanism).

However, it must be taken into account that to be able to reduce polluting emissions and maintain, at the same time, a high standard of living in the society, a balance must be kept between different policies and this often implies important economic effects.

In this context, it would be necessary to assess these emissions, both in general and specifically, by pollutants and/or among productive sectors. The object of this paper is precisely to estimate the polluting emissions of industrial origin in Catalonia in the year 2001, four directly related to greenhouse effect (CH_4, CO, CO_2, N_2O) and two photochemical air pollutants (NMVOC, NO_x). This is done in a multivariate context which explicitly allows a distinction to be made between the polluter and/or the productive sector causing this emission.

Following a brief introduction in this section, the methods, variables and data used are described in Section 2. In Section 3, the results are shown and, finally, these are discussed and some conclusions are made in Section 4.

2. Methods

2.1. Data

All the data was obtained from the input-output Tables for Catalonia in the year 2001, *TIOC-01* (IDESCAT, 2007).[2]

Pollutants considered were six, five related to greenhouse effect and one (non-methane volatile organic compounds) that corresponds to photochemical pollution.

2.2. Statistical analysis

In accordance with Mizobuchi and Kakamo (2007), it can be assumed, in the first place, that the pollutant emission is a function of production,

$$POL_i = f(Y_i) \qquad [1]$$

where POL indicates the vector of the pollutants, $POL = (CH_4, CO, CO_2, NMVOC, NO_x, N_2O)'$, CH_4 being methane; CO carbon monoxide; CO_2 carbon dioxide; NMVOC non-methane volatile organic compounds; NO_x nitrogen oxides; N_2O nitrous oxide; and the sub-index i indicates the sector (i=1,…,26, see Table 1).

Following the hypothesis of Environmental Kuznets Curve, this function should not be specified in a linear way, but mainly as an inverted *U* (Panayotou, 2000; Strazicich and List, 2003). In a preliminary analysis, however, both this and other non-linear specifications[3] had a worse adjustment than the following linear specification[4]:

[2] Atmospheric polluting emissions of Catalonia by sectors, from the Corine-air inventory (Ministerio de Medio Ambiente), produced by Vicent Alcántara for the Project on Environmental Accounts in Catalonia. Information provided by the author.
[3] In particular, *restricted cubic splines* with different degrees of freedom (see Harrell *et al.*, 1988).
[4] Results not shown can be supplied by the authors.

$$POL_i = \gamma Y_i \quad [2]$$

where γ is a vector of unknown parameters.

Following Romer's production function (1986),

$$Y_i = A_i K_i^{\beta} \quad [3]$$

it is also assumed that there is no growth in population.[5]

Here *A* represents technological progress and *K* the capital.

Following several analyses, the econometric model was specified as the following multi-level model (see Saez, 2001) (see footnote 4):

$$\log(POL)_{ij} = \log(A)_j + \beta_i \log(K)_{ij} + u_{ij} \quad [4]$$

Indicating a perturbation end with *u* and in which both technological progress (*A*), and elasticity of capital (β) were introduced as random effects, the technological progress specific-pollutant (*j* being the sub-index which indicates the pollutant, and the elasticity of capital specific-sector (*i* being the sub-index which indicates the sector).

$$\log(A)_j = \log(A) + \varepsilon_j$$
$$\beta_{1i} = \beta + \omega_i$$

where ε *and* ω are random perturbations with a mean of zero and constant variance.

[5] This is an acceptable assumption in this paper, since transversal cuts were used.

The model was estimated based on restricted maximum likelihood (Patterson and Thompson, 1971; Lindstrom and Bates, 1988; Bates and Pinheiro, 1998).

Estimates were carried out in the *R* environment of free software (version 2.6.0) (R Development Core Team, 2007).

3. Results

In Table 1 some descriptions of gross data, both of the analysed pollutant emissions and the capital of the 26 productive sectors, are shown.

The pollutant with greater volume of emissions was methane, CH_4 (11,044 million tons), followed by non-methane, volatile, organic compounds, NMVOC (10,040 million tons). Carbon dioxide, CO_2 (1,176 million tons) and nitrous oxide, N_2O (3,122 million tons) were the pollutants with fewer emissions from among those analysed in this paper. Dispersion was significant in all cases, with coefficients of variation in a range between 2.008 (carbon dioxide, CO_2) and 3.557 (carbon monoxide, CO).

Regarding the capital, the average capital was 2,190 million euros (the median equals 1270 million euros, first quartile equals 632, and third quartile equals 2092). Only six sectors had an above-average capital, the public services sector standing out with 12,616 million euros. Of the 20 sectors with a below-average capital, the chemistry sector (57 million euros) and, to a lesser degree, electrical equipment, electronics and optics (163 million) stand out.

In Table 2 the results of the model estimates are shown. The estimator of technological progress (average) was estimated as equivalent to the emission of 5,974 thousand tons (median equals 2620 thousand tons). In NMVOC, nitrogen oxides (NO_x) and nitrous oxide (N_2O), above-average technical progress was estimated (see Fig. 1a), although the difference was only statistically significant in

the latter case ($p<0.05$). In the rest of pollutants, a below-average technical progress was estimated, although only in the cases of methane ($p<0.05$) and, marginally in the case of carbon dioxide ($p<0.1$), were these differences statistically significant (with respect to the median).

Capital elasticity was estimated as clearly non-elastic, 0.3637. Commerce, agriculture, personal services, food, financial intermediation and construction had an elasticity of capital greater than 0.5 (Table 3). Transport and communications, homes that employ domestic staff, energy products, minerals, coke, petroleum and fuels, education and electrical energy, gas and water were the other sectors with an above-average elasticity of capital (Table 3). Among the sectors with a below-average elasticity of capital, the paper sector (elasticity equals 0.162) and rubber and plastic products (in this case elasticity was estimated at 0.189) stand out.

However, a great variability can be observed, both in technical progress per pollutant (Fig. 1a) and in capital per sector (Fig. 1b) (see also standard error confidence interval of random errors in Table 2).

Finally, in Table 4, estimations of the emissions of the pollutants per productive sector are shown. Thus, in a decreasing order of emissions, the estimated emission of NMVOC was 6772 million tons, with construction (71,378 million), Housing (20,437 million), homes that employ domestic staff (19,917 million), personal services (11,418 million) and the materials transportation industry (7,819 million) with above-average estimated emissions. The productive sectors, on average, were estimated to emit 6387 million tons of methane (CH_4). It was estimated that agriculture (93,715 million tons), transport and communications (50,217 million) and construction (17,486 million) emitted much more methane than the average. An emission of 4285 tons of carbon monoxide (CO) was estimated, with paper (69,661 million), homes that employ domestic staff (11,447 million), the chemistry industry (8917 million) and hotel management (6035 million) being the sectors in which above-average emissions were estimated. An emission of 4137

million tons of nitrogen oxides (NO_x) was estimated. In this case, the plastics industry (35,950 million), the materials transportation industry (15,885 million), electrical equipment, electronics and optics (11,539 million), education (11,136 million), hotel management (9261 million) and commerce (5541 million) were the sectors with above-average emission estimations. The estimated emissions of nitrous oxide were 2620 million tons. The above-average estimated nitrous oxide emissions were energy products, minerals, coke, petroleum and fuels (19,553 million), manufacture of wood and cork (12,423 million), social services, sanitary and veterinary activities (11,624 million), machinery (8101 million) and financial intermediation (4546 million). Carbon dioxide (CO_2) emission was estimated at 1196 million tons. Sectors with above-average CO_2 emissions were public services (7753 million), hotel management (7673 million), education (4646 million), food (3048 million) and electrical energy, gas and water (2194 million).

The fishing industry, the metal industry, the sector of other industries and that of non-metallic mineral products were the only sectors with below-average estimates in each and every one of the pollutants.

4. Discussion

In this paper, emissions from pollutants of industrial origin in Catalonia in 2001 in a multivariate context have been estimated. In particular, a multi-level model has been used with two levels, the pollutant and the productive sector. The parameters of the model, the technical progress and the elasticity of capital have denoted the random effects. Thus, they have permitted as much one as the other, to vary according to one or other level, the technical progress according to the pollutant, and the elasticity of capital according to the productive sector.

The most important finding in this paper is that elasticity of capital has been estimated as very non-elastic, with a range which varies between 0.162 (the paper industry) and 0.556 (commerce). In fact, and generally speaking, the greater

capital the sector has, the less elasticity of capital has been estimated. As a logical exception, the sectors related to services do not follow this general rule.[6]

On average, the estimated volume of emissions was, in decreasing order, NMVOC with 6772 million tons; methane (CH_4), 6387 million tons; carbon monoxide (CO), 4285 million tons; nitrogen oxides (NO_x), 4137 million tons; nitrous oxide (N_2O), 2620 million tons; and carbon dioxide (CO_2), 1196 million tons.

The hotel management sector is the one which has above-average estimated emissions for a greater number of pollutants, nitrogen oxides (NO_x), carbon dioxide (CO_2) and carbon monoxide (CO). The above-average emissions in two of the analysed pollutants were estimated in construction (NMVOC and CH_4), education (HFC and CO_2); homes that employ domestic staff (NMVOC and CO), the materials transportation industry (NMVOC and NO_x). The rest of the sectors either exceed the estimated emissions in one of the pollutants or the estimated volume of emissions is below-average in all cases, as in the fishing industry, the metal industry, the sector of other industries, and that of other non-metallic mineral products.

Take note that in the services sectors a quite high volume of emissions of nitrogen oxides (NO_x), carbon dioxide (CO_2) and carbon monoxide (CO) (in that order) was estimated. However, in the industrial sectors, high emissions were estimated in all pollutants, the predominance of one or another depending on capital intensity. For example, for the sector of energy products, minerals, coke, petroleum and fuels, with a capital of 1047 million euros, an emission of 19,533 million tons N_2O was estimated. However, in industrial sectors with greater capital, the metal industry, the sector of other industries and the non-metallic mineral products industry, the estimated emission never exceeded the average.

[6] Thus, see other services and social activities with a capital of 5,079 million euros and an elasticity of capital of 0.542.

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Table 1.- Description of emissions and capital of the productive sectors.

Emissions[a]

Pollutants	Mean	Std. deviation	Median	Q1 (25^{th})	Q3 (75^{th})
Methane, CH_4	11,044.2	36,143.4	21.5	8.0	211.0
Carbon monoxide, CO	5561.7	19,784.0	214.0	83.0	708.0
Carbon dioxide, CO_2	1175.6	2361.1	176.5	86.0	492.0
Non methane volatile organic compounds, NMVOC	10,040.3	22,717.8	2688.5	37.0	8,788.0
Nitrogen oxides, NO_x	4747.8	10,022.7	981.0	247.0	2314.0
Nitrous oxide, N_2O	3122.2	6597.5	444.5	243.0	1049.0

[a] Thousands of tons

Capital

Productive sectors	Thousands of Euros
Agriculture	1,969,524
Chemistry	56,608
Commerce	307,468
Construction	1,189,201
Education	1,730,576
Electrical energy, gas and water	991,339
Electrical equipment, electronics and optics	162,784
Energy products, minerals; coke, petroleum and fuels	1,046,972
Financial intermediation	2,092,418
Fishing	631,507
Food	769,894
Homes that employ domestic staff	1,448,833
Hotel management	992,051
Machinery	1,057,297
Manufacture of transport material	1,349,838
Manufacture of wood and cork	277,352
Metal	3,991,980
Other industries	7,929,001
Other non-metallic mineral products	4,095,448
Other services and social activities; personal	5,079,222
Paper	2,738,336
Public services	12,615,685
Real estate activities and entrepreneurial services	524,738
Rubber and plastic products	569,510
Sanitary and veterinary activities; social services	1,415,289
Transport and communications	189.499,1

Table 2.- Results of the estimation of the model

	Coefficients	Standard error	IC 95%
Fixed effects			
Technical progress	5.97400		
Capital[a]	0.36370		
Random effects			
Technical progress (per pollutant)		1.61954	0.02656-98.7487
Capital (per sector)[a]		0.12990	0.09361-0.18027

Standard error of the model	0.71349
AIC	681.07
BIC	696.25

[a] Elasticity

Table 3.- Elasticity of capital per productive sector

Productive sectors	Elasticity
Commerce	0.5562694
Agriculture	0.5427474
Other services and social activities; personal	0.5423769
Food	0.5362701
Financial intermediation	0.5131578
Construction	0.5053491
Transport and communications	0.4435312
Homes that employ domestic staff	0.4261068
Energy products, minerals; coke, petroleum and fuels	0.4019234
Education	0.3986370
Electrical energy, gas and water	0.3917263
Estimated elasticity (mean)	0.3637000
Manufacture of wood and cork	0.3599079
Manufacture of transport material	0.3491512
Other industries	0.3394910
Fishing	0.3376152
Chemistry	0.3202694
Electrical equipment, electronics and optics	0.3142722
Metal	0.3091455
Machinery	0.3046418
Hotel management	0.3023085
Public services	0.2516396
Other non-metallic mineral products	0.2269864
Real estate activities and entrepreneurial services	0.2243526
Sanitary and veterinary activities; social services	0.2070013
Rubber and plastic products	0.1894189
Paper	0.1620125

Descending order

Table 4.- Estimated emissions of pollutants per productive sector

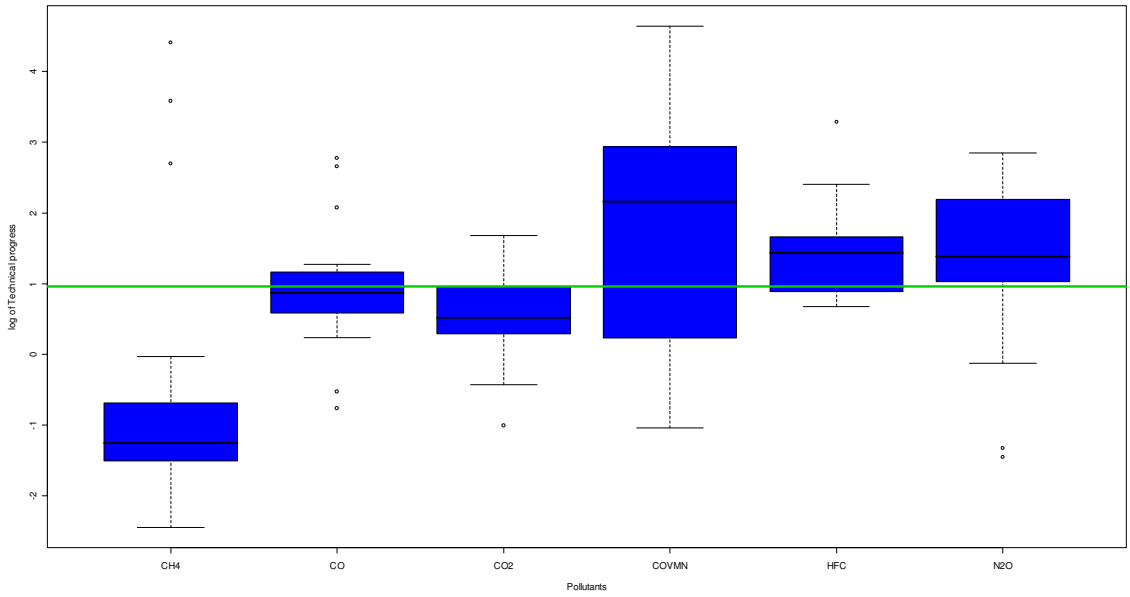
Productive sectors	**NMVOC**	**CH_4**	**CO**	**NO**	**N_2O**	**CO_2**
Agriculture	49.072	**93715.159**	---	4.343	42.565	283.953
Chemistry	397.150	6.496	**8917.250**	7.135	25.644	---
Commerce	---	518.592	82.344	**5540.822**	40.707	952.117
Construction	**71377.581**	**17486.398**	3262.421	---	1279.272	87.300
Education	41.859	90.030	696.496	**11135.905**	---	**4645.969**
Electrical energy, gas and water	2238.999	51.825	711.295	890.065	608.663	**2194.137**
Electrical equipment, electronics and optics	5321.881	12.122	435.358	**11538.887**	75.643	524.413
Energy products, minerals; coke, petroleum and fuels	2525.730	63.822	78.106	3529.517	**19553.207**	305.978
Financial intermediation	4916.215	1701.077	492.164	1917.707	**4545.701**	70.970
Fishing	229.481	24.421	3303.621	1169.132	1341.307	390.006
Food	5717.271	331.622	153.781	214.323	768.603	**3047.672**
Homes that employ domestic staff	**19917.228**	64.680	**11446.774**	1342.715	192.297	138.425
Hotel management	901.596	14.284	**6035.025**	**9261.090**	964.083	**7673.390**
Machinery	1968.795	17.040	91.805	421.498	**8101.442**	542.891
Manufacture of transport material	**7819.121**	28.853	102.748	**15885.222**	376.903	87.150
Manufacture of wood and cork	1045.744	17.848	175.095	1222.834	**12423.178**	95.372
Metal	803.675	9.509	165.368	251.880	990.281	185.443
Other industries	5491.003	49.059	393.357	281.370	224.939	117.127
Other non-metallic mineral products	2507.950	16.173	441.208	480.954	251.696	143.702
Other services and social activities; personal	**11417.670**	1561.734	101.843	439.921	429.870	284.631
Paper	4130.298	5.430	**69660.501**	1010.327	254.737	88.234
Public services	12.710	33.282	30.167	677.820	29.085	**7753.476**
Real estate activities and entrepreneurial services	**20437.085**	9.492	206.459	73.363	928.349	26.036
Rubber and plastic products	4.267	5.527	59.775	**35949.702**	332.106	179.505
Sanitary and veterinary activities; social services	26.448	9.457	35.610	21.771	**11623.528**	51.720
Transport and communications	7.161	**50217.401**	56.368	148.407	98.921	31.533

Averages	6772	6387	4285	4137	2620	1196

Thousands of tons higher than the average are highlighted in bold.

Figure 1.- Estimations of random effects

Figure 1a.- Technical progress per pollutant[1]



[1] **log (technical progress)**

Figure 1b.- Elasticity of capital per sector