3 SPATIAL ECONOMETRICS – APPLICATIONS TO INVESTIGATE DISTRIBUTION OF CO_2 EMISSION IN EUROPE[*]

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Abstract

Over the last decade economists were more and more concentrated on studying the impact of the greenhouse effect on economy. At the same time, they tried to find solutions to stop the CO_2 emissions into the atmosphere and, implicitly, to make changes in the structure of energy production and consumption. This challenge forced them to use new models and methods in order to estimate more accurately the future economic development. Among the special tools, the so-called spatial econometrics begun to be used for studying, for example, the distribution of gas emissions in extended geographical zones, but also to quantify their implication at the macroeconomic level. Using available data, in this study we try to build a simple model dedicated to estimate on medium and long terms some likely major changes in the macroeconomic correlations under the circumstances of increase in the total quantity of CO_2 emissions in the atmosphere and how that will influence the economic growth in the future. Certainly, under the unchanged actual technological conditions the growth rate of the economies in Europe or even worldwide could be dramatically affected at least in the long run by stronger restrictions on CO_2 emission and on its corollary - production and consumption of energy resources.

Keywords: Spatial Econometrics, CO_2 Emission, Three-Dimensional Map, Contour Plot, Distribution

JEL Classification: C46, E17, O11, Q43, Q54

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1. Introduction

Lately, the economists have come closer and closer to specialists from natural science disciplines to study the impact of human activity on environment and on dramatic climate change. Within this framework, the most significant factor responsible for accelerating the so-called greenhouse effect is unanimously considered the increase in the CO_2 emission in atmosphere.

Moreover, based on empiric evidences, the emission of CO_2 into atmosphere is recognised nowadays to be a consequence of the general process of economic development and of its corollary - the increase in the energy production and consumption, at least in the case of maintaining the actual stage of technology. More concretely, in today's world the economic development is supported by increased production and consumption of energy.

Consequently, to stop the increase in CO_2 emission into the atmosphere could be equivalent to limit the development process, which is non-acceptable at least for actually less developed countries. The single reasonable solution to this dilemma is to concentrate on the rise in the level of efficiency in using energy resources as the main factor of economic growth; however, that will imply huge efforts coming from daily domestic activity to the research in technological development.

In order to estimate the future dynamics of the CO_2 emission into the atmosphere, firstly it is needed to study certain macroeconomic correlations related to production and consumption of energy. Then, based on empirical data in the European countries, we shall estimate few essential parameters that determine the quantity of CO_2 emission in atmosphere related to the general level of economic development.

2. Hypotheses, indicators, and empirical evidence in the EU

Empirical data on the European Union (27 countries, since 1st January, 2007) demonstrated certain important correlations among the level of economic development, energy consumption and CO_2 emission into the atmosphere. In this respect, we present the level of some essential indicators in Appendix 1, where the listed countries are ordered by the GDP per capita in 2000. Also, Figures 1-4 show graphically some of the main distributions in the European Union in 2000 related to the specific quantity of CO_2 emissions and to that of consumption of energy, respectively. The specific indicators used and their measurement units are as follows:

y = Y/P (GDP in USD current prices, Y, per number of population, P)

e = E/P (primary energy consumption, in kg oil equivalent, E, per inhabitant)

eY = E/Y (primary energy consumption per GDP)

el = El/P (consumption of electric power, in Kwh, El, per inhabitant)

em = Em/P (CO_2 emission, in metric kg, Em, per inhabitant)

emY = Em/Y (CO_2 emission per GDP)

emE = Em/E (CO_2 emission per primary energy consumption)

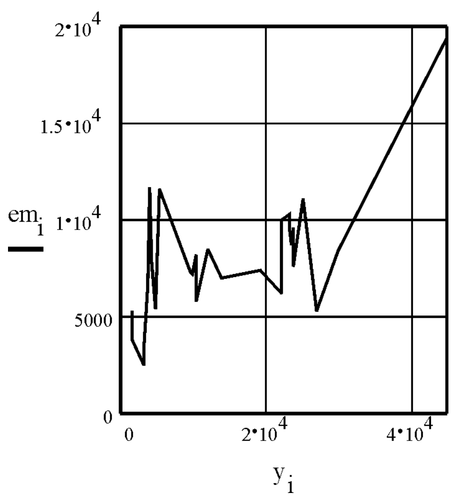
d = P/S (number of population per area, in km^2, S)

As a general correlation, the empirical data show that an increase in the economic development level is accompanied by a similar increase in the consumption of energy resources (energy being in fact one of the basic factors of economic growth in modern era). Unfortunately, under technological conditions existing today, the growth of energy consumption is generally followed by amplification of CO_2 emission into the atmosphere. Consequently, as graphical representations in Figure 1 suggest, the distributions of the specific indicators per inhabitant, function of economic development level (GDP per capita), are similar in case of CO_2 emission (em) and energy consumption, respectively.

Other two specific indicators significant for analysing the correlations at the aggregate level are specific CO_2 emissions per unit of GDP (emY) and per unit of primary energy consumption (eY), respectively. Their distribution in the European Union is graphically presented in Figure 2. Also, Figure 3 shows the distribution of specific the consumption of electric power per capita (el) and that of primary energy consumption per unit of GDP (eY), respectively, both of them as a function of the economic development level. Finally, Figure 4 shows the distribution of the specific CO_2 emission per capita function of primary energy consumption per inhabitant (e) and, separately, the function of electric power consumption per capita (el).

Moreover, from the viewpoint of the harmful effect of gas emission and pollution, the size of a country's area and, implicitly, of the density of population could be significant. However, at least in the case of the EU there is not a strong relationship between the density of the population and the level of the economic development (there are countries registering a high level of GDP per inhabitant and low density of population, as Finland and Sweden do, but at the same time there are countries with a high level of GDP per capita and high density of population, as Belgium, Denmark, Germany, the Netherlands, and the UK).

Figure 1



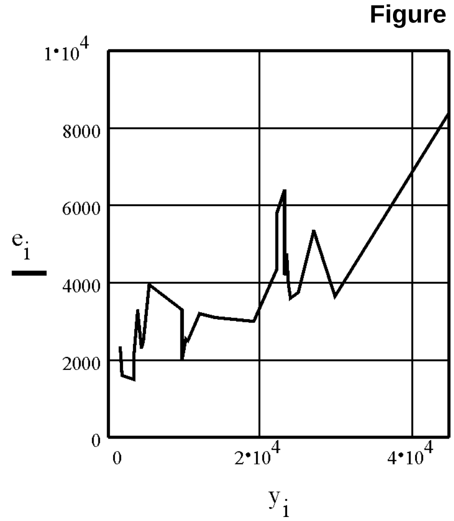


Figure 2

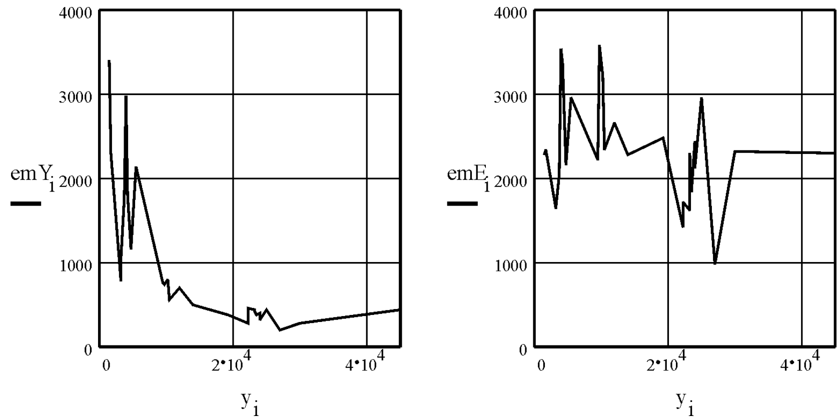


Figure 3

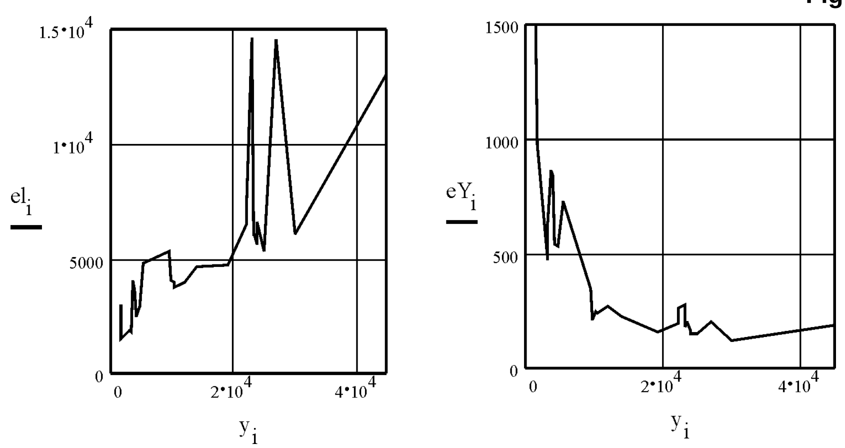
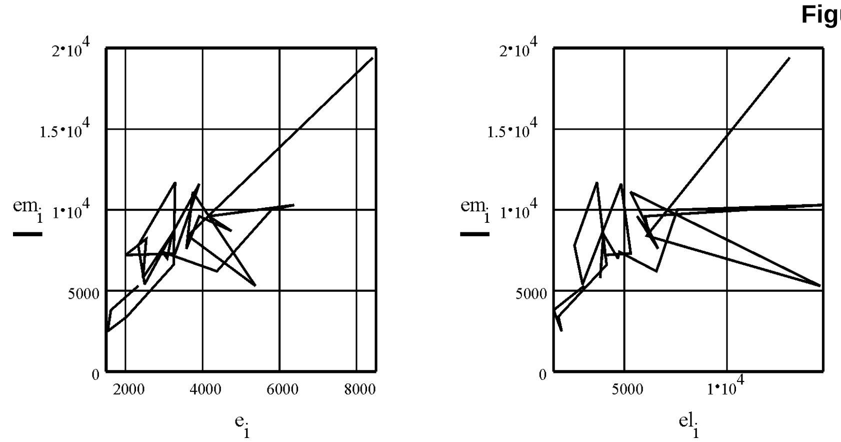


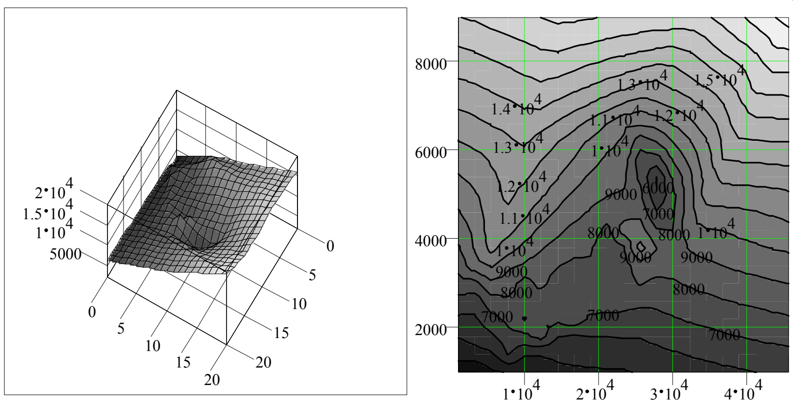
Figure 4



3. Three-dimensional maps and complex correlations

In order to estimate the future economic evolution of the EU it is useful to make a more refined analysis of the complex correlations which set up at macroeconomic level related to the absolute volume of CO_2 emission into the atmosphere and a series of specific indicators. In this sense, we considered some 3D representations by using a special technique such as that of the potential functions. For example, we present in Figures 5-7 the 3-dimensional pictures of the main correlations existing in 2000 in the European Union among the main variables implied at the aggregated level in the process of modelling the CO_2 emission. In the case of each selected correlation, we also present the attached so-called geodesic map or contour plot.

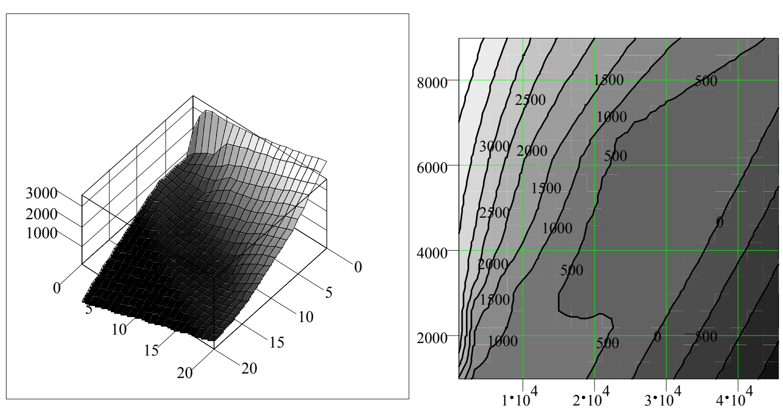
Figure 5



y, e, em   y, e, em

min(y) = 1555.6   min(e) = 1521.9   min(em) = 2500
max(y) = 44748.9   max(e) = 8408.7   max(em) = 19400

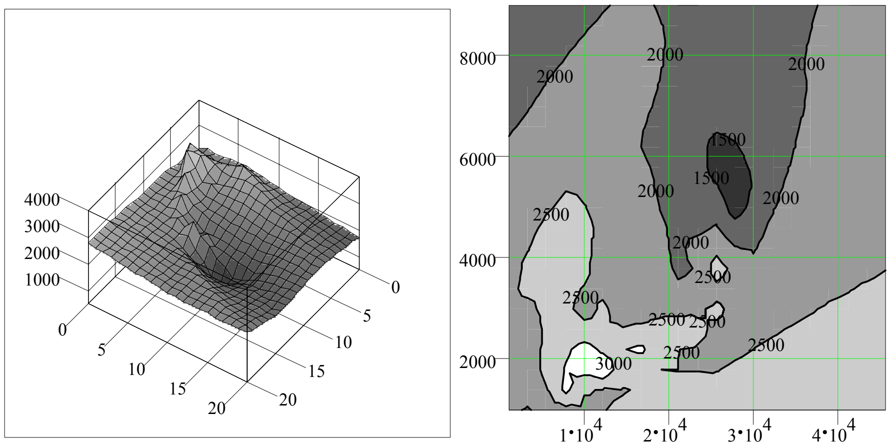
Figure 6



y, e, emY   y, e, emY

min(y) = 1555.6   min(e) = 1521.9   min(emY) = 196.9
max(y) = 44748.9   max(e) = 8408.7   max(emY) = 3407.1

Figure 7



y, e, emE y, e, emE

min(y) = 1555.6 min(e) = 1521.9 min(emY) = 989.6

max(y) = 44748.9 max(e) = 8408.7 max(emY) = 3577.1

Considering to the spatial distribution in European Union, the graphic representations in Figure 5 suggest that, without the commonplace case of a very low GDP per capita (below 2000 USD per inhabitant), the minimal emissions of CO_2 (the dark zone delimitated by the contour line of 6000 Kg CO_2 per capita in the case of variable em) could be achieved for values of y located around the level of 28000 USD per capita and, simultaneously, for an amount of primary energy consumption, e, of about 5000 kg of oil equivalent per capita.

The graphic representations in Figure 6 demonstrate that in the long run the single viable solution in order to diminish the specific emission of CO_2 into the atmosphere per unit of GDP is economic development itself (see the region bordered by the contour line of 500 tons of CO_2 per one million GDP, for which its extreme contour line in the left part of the map corresponds to values of y around 15000 USD per inhabitant; on this map it is needed to ignore the dark zone where variable emY is negative, resulting only from the simulation of the theoretic model applied to available data and having no sense from the economic viewpoint).

In the two graphic representations in Figure 7 one may see two small extreme zones: 1) abyssal area – dark area delimitated by the contour line of 1500 kg CO_2 per tep (ton oil equivalent) for the variable emE, which corresponds simultaneously to values of y located between 25000 and 30000 USD per capita and to values of variable e between 4700 and 6500 kg oil equivalent per capita, respectively; 2) top area – white area bordered by the contour line of 3000 kg CO_2 per tep for variable emE, which corresponds simultaneously to values of y located between 7000 and 13000 USD per capita and to values of variable e between 1400 and 2300 kg oil equivalent per capita, respectively.

4. Spatial econometric model and simulations

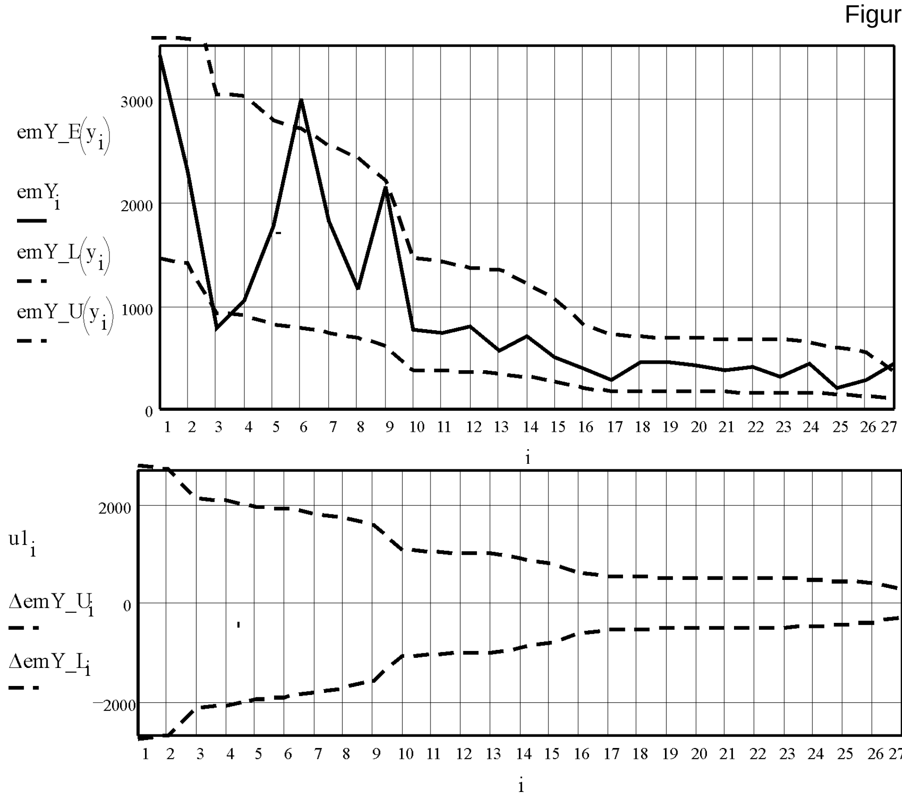
In order to estimate a robust relationship available for the long-term forecasts between the CO_2 emission and GDP we used the inverse correlation already demonstrated empirically (see the left graphic representation in Figure 2) and the "concentration-inhibition" model, a theoretical model in which y (GDP per inhabitant) play the role of inhibitor ("inhibitor dose"). Thus, we selected the corresponding regression equation, as follows:

$$emY(y) = [(a1 \cdot b1) / (a1 + y)] + u1 \quad (1)$$

where a1, b1 are parameters estimated econometrically, and u1 is the residual.

Some results of the regression are presented graphically in Figure 8, where together with the spatial distribution of variable emY in the European Union, in 2000, and its estimation, emY_E, it shows the two curves of lower values, emY_L, and upper values, emY_U, respectively, which delimitate the statistical confidence interval (95%) and are depicted as dashed lines, as well as the residual curve on the second graphic representation. Index i on the abscissa means countries in the European Union in increasing order by the level of GDP per inhabitant in 2000 (i=1, …, 27). Detailed results of this regression model are presented in Appendix 2.

Figure 8



Combining the above regression equation with the definition relation of the specific CO_2 emission per capita we obtained the following theoretical expression for estimating the variable em:

$$em1\_E(y) = [(a1 \cdot b1 \cdot y) \cdot (1/1000)] / (a1 + y)$$

where: em1_E are the estimated values of em, based on a1 and b1 coefficients computed previously, and the factor 1/1000 is a correction coefficient due to the measurement units used.

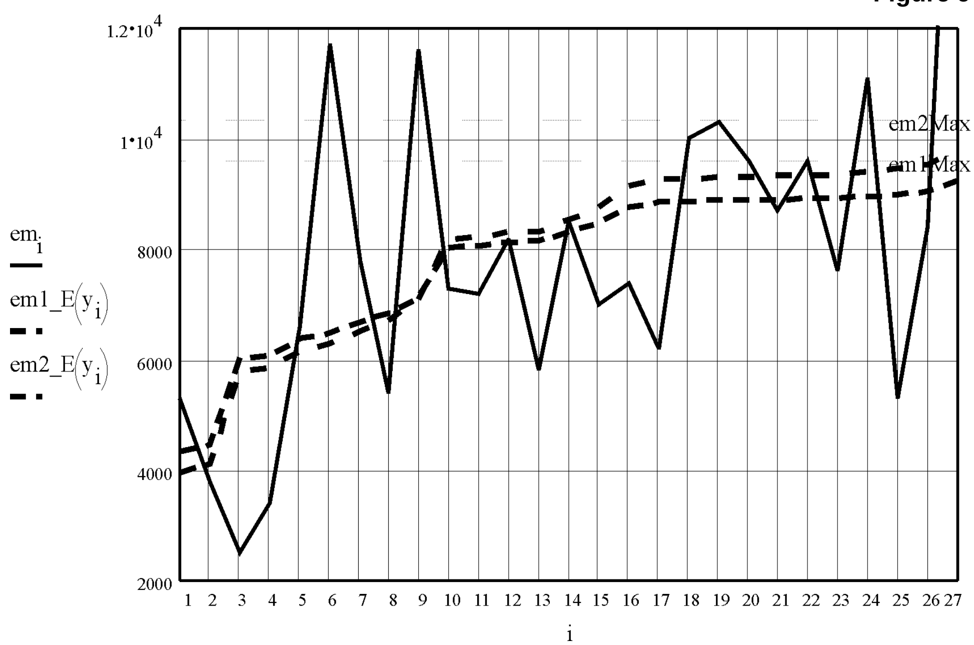
Moreover, we estimated directly the function of em(y) based on the following regression equation:

$$em(y) = [(a2 \cdot b2 \cdot y) / (a2 + y)] + u2$$

where: a2, b2 are parameters estimated econometrically, and u2 is the residual in this case.

Corresponding to this regression equation, we obtained a second set of estimates of em, denoted now by em2_E. As one may see from the graphical representation in Figure 9, the estimates generated by the two functions used are very close (except for the case of the second individual equation when the results of the regression are somehow weaker than in that of using the regression equation for emY, as it is shown in Appendix 3).

Figure 9



Other conclusion derived from the data is the very high value of CO_2 emission in the case of Luxembourg (i=27) as compared to the average EU level (moreover, referring to the value of GDP per inhabitant, this country is again much beyond the other countries in the EU). In order to eliminate such impediment, we could conceive some other various estimation procedures, either by excluding this country from the series or by considering it together with Belgium (or together with Belgium and the Netherlands).

In the graphs in Figure 9 are also depicted two theoretical asymptotes corresponding to the two considered regression equations towards which the CO_2 emission tends when GDP per capita increases up to higher and higher levels, em1Max=9622.028 and em2Max=10337.292, respectively (by excluding Luxembourg from series, em2Max goes down to a value of only 9059.086 kg CO_2 per capita).

References

Albu, L.-L. (1990): "Industry-Agriculture Relationship and Its Impact on the Environment", *International Conference on Food Problems in Developing Countries and the Potential Contribution of R&D to Their Solution*, December, CINADCO, Tel Aviv.

Albu, L.-L. (1991): "*Raportul industrie-agricultura si dezvoltarea economica*" (*Industry-Agriculture Relationship and Economic Development)*, Doctoral Thesis, Romanian Academy, INCE, Bucharest.

Albu, L.-L. (2006): "Corelații la nivel macroeconomic" (Correlations at Macroeconomic Level)*, Modele avansate de prognoză tehnico-economice specifice României pentru emisiile de gaze cu efect de seră, Program de Cercetare de Excelență*, Faza II, iunie 2006, Institutul de Prognoză Economică, Academia Română.

Lecocq, F. and Crassous, R. (2003): "International Climate Regime Beyond 2012. Are Quota Allocation Rules Robust to Uncertainty?", *World Bank Policy Research Working Paper*, No. 3000, March, The World Bank, Development Research Group.

Lecocq, F. and Z. Shalizi, Z. (2004): "Will the Kyoto Protocol Affect Growth in Russia?", *World Bank Policy Research Working Paper*, No. 3454, November, Development Research Group.

Power, T. M. (2001): "The Impact of Proposed Greenhouse Gas Control Policies on Coal Mining and Railroad Employment", *Paper prepared for The Economic Policy Institute*, Washington, DC, August.

Stern, D. I. (2004): "Diffusion of Emissions Abating Technology", *Rensselaer Working Paper in Economics*, No 0420, September, Rensselaer Polytechnic Institute, Troy, NY, USA.

Appendix 1

Indicators of economic development, energy consumption and CO_2 emission in 2000, in the European Union

		y=Y/P	e=E/P	el=El/P	em=CO2/P	emY=CO2/Y	emE=CO2/E	d=P/S
		GDP per capita (in USD)	Kg oil equivalent per capita	KWh per capita	Kg CO_2 per capita	Tons CO_2 per one million USD	Kg CO_2 per Ton oil equivalent	Inhabitants per km^2
	World	**5180.3**	**1692.3**	**2173.7**	**3800**	**733.5**	**2245.5**	**45.6**
	EU	**17200.4**	**3558.1**	**5236.8**	**7822**	**454.8**	**2198.4**	**111.4**
1	Bulgaria	1555.6	2330.4	3008.8	5300	3407.1	2274.3	73.0
2	Romania	1656.3	1618.4	1512.2	3800	2294.3	2348.0	94.0
3	Latvia	3208.3	1521.9	1887.4	2500	779.2	1642.7	37.2
4	Lithuania	3257.1	2049.9	1768.0	3400	1043.9	1658.6	53.6
5	Slovakia	3740.7	3240.2	4082.7	6600	1764.4	2036.9	110.6
6	Estonia	3928.6	3302.7	3628.3	11700	2978.2	3542.6	31.0
7	Poland	4313.5	2317.0	2511.2	7800	1808.3	3366.4	123.4
8	Hungary	4670.0	2495.3	2937.1	5400	1156.3	2164.1	107.5
9	Czech Rep.	5407.8	3930.3	4806.7	11600	2145.1	2951.4	130.6
10	Slovenia	9550.0	3288.6	5289.6	7300	764.4	2219.8	98.8
11	Malta	9743.6	2012.8	4017.9	7200	738.9	3577.1	1218.8
12	Greece	10284.4	2548.4	3952.6	8200	797.3	3217.7	82.6
13	Portugal	10441.2	2475.8	3750.7	5800	555.5	2342.7	110.9
14	Cyprus	12021.1	3203.4	3957.7	8500	707.1	2653.4	81.8
15	Spain	13871.6	3078.3	4653.3	7000	504.6	2274.0	80.0
16	Italy	19064.1	2976.8	4731.8	7400	388.2	2485.9	191.5
17	France	22071.3	4373.6	6539.2	6200	280.9	1417.6	106.8
18	Belgium	22165.0	5785.3	7563.6	10000	451.2	1728.5	337.6
19	Finland	23057.7	6379.2	14594.4	10300	446.7	1614.6	15.4
20	Germany	23114.4	4178.9	5963.1	9600	415.3	2297.3	230.3
21	The Netherlands	23308.2	4741.8	6152.3	8700	373.3	1834.7	382.9
22	England	23769.1	3925.5	5594.8	9600	403.9	2445.5	242.5
23	Austria	23800.0	3598.5	6574.6	7600	319.3	2112.0	95.4
24	Ireland	24947.4	3758.7	5297.6	11100	444.9	2953.1	54.1
25	Sweden	26921.3	5355.6	14514.0	5300	196.9	989.6	19.8
26	Denmark	29849.1	3635.6	6076.4	8400	281.4	2310.5	123.0
27	Luxemburg	44748.9	8408.7	13050.2	19400	433.5	2307.1	169.4

Appendix 2

Number of observations = 27
Number of missing observations = 0
Solver type: Nonlinear
Nonlinear iteration limit = 250
Diverging nonlinear iteration limit =10
Number of nonlinear iterations performed = 16
Residual tolerance = 0.0000000001
Sum of Residuals = 69.6058789708456
Average Residual = 2.57799551743873
Residual Sum of Squares (Absolute) = 5250380.86201724
Residual Sum of Squares (Relative) = 5250380.86201724
Standard Error of the Estimate = 458.274191375305
Coefficient of Multiple Determination (R^2) = 0.7306972412
Proportion of Variance Explained = 73.06972412%
Adjusted coefficient of multiple determination (Ra^2) = 0.7199251309
Durbin-Watson statistic = 1.50731009338346

Regression Variable Results

Variable	Value	Standard Error	t-ratio	Prob(t)
a1	1903.873517	976.7694498	1.949153424	0.06258
b1	5053.921927	1633.500301	3.093921637	0.00481

68% Confidence Intervals

Variable	Value	68% (+/-)	Lower Limit	Upper Limit
a1	1903.873517	991.0302837	912.8432335	2894.903801
b1	5053.921927	1657.349406	3396.572521	6711.271333

90% Confidence Intervals

Variable	Value	90% (+/-)	Lower Limit	Upper Limit
a1	1903.873517	1668.419897	235.4536201	3572.293414
b1	5053.921927	2790.181865	2263.740062	7844.103792

95% Confidence Intervals

Variable	Value	95% (+/-)	Lower Limit	Upper Limit
a1	1903.873517	2011.656682	-107.7831645	3915.530199
b1	5053.921927	3364.193871	1689.728056	8418.115798

99% Confidence Intervals

Variable	Value	99% (+/-)	Lower Limit	Upper Limit
a1	1903.873517	2722.647164	-818.773647	4626.520682
b1	5053.921927	4553.21874	500.7031865	9607.140667

Variance Analysis

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob(F)
Regression	1	14245820.68	14245820.68	67.83232045	0
Error	25	5250380.862	210015.2345		
Total	26	19496201.55			

Appendix 3

Number of observations = 27
Number of missing observations = 0
Solver type: Nonlinear
Nonlinear iteration limit = 250
Diverging nonlinear iteration limit =10
Number of nonlinear iterations performed = 40
Residual tolerance = 0.0000000001
Sum of Residuals = 394.38079395664
Average Residual = 14.6066960724681
Residual Sum of Squares (Absolute) = 214720990.358361
Residual Sum of Squares (Relative) = 214720990.358361
Standard Error of the Estimate = 2930.67221202482
Coefficient of Multiple Determination (R^2) = 0.2457637975
Proportion of Variance Explained = 24.57637975%
Adjusted coefficient of multiple determination (Ra^2) = 0.2155943494
Durbin-Watson statistic = 1.59292865727257

Regression Variable Results

Variable	Value	Standard Error	t-ratio	Prob(t)
a2	2517.094292	1439.863912	1.748147357	0.09271
b2	4.106835443	1.971180818	2.083439229	0.04759

68% Confidence Intervals

Variable	Value	68% (+/-)	Lower Limit	Upper Limit
a2	2517.094292	1460.885925	1056.208366	3977.980217
b2	4.106835443	1.999960058	2.106875386	6.106795501

90% Confidence Intervals

Variable	Value	90% (+/-)	Lower Limit	Upper Limit
a2	2517.094292	2459.431548	57.66274355	4976.52584
b2	4.106835443	3.366973955	0.7398614886	7.473809398

95% Confidence Intervals

Variable	Value	95% (+/-)	Lower Limit	Upper Limit
a2	2517.094292	2965.399727	-448.3054351	5482.494018
b2	4.106835443	4.059646894	0.04718854929	8.166482338

99% Confidence Intervals

Variable	Value	99% (+/-)	Lower Limit	Upper Limit
a2	2517.094292	4013.476668	-1496.382377	6530.57096
b2	4.106835443	5.494469411	-1.387633968	9.601304855

Variance Analysis

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob(F)
Regression	1	69965676.31	69965676.31	8.146115127	0.00855
Error	25	214720990.4	8588839.614		
Total	26	284686666.7			