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The determinants of CO_2 emissions: evidence from European countries

Economics Department

Rafael Morales-Lage
Aurelia Bengochea-Morancho
Inmaculada Martínez-Zarzoso

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Rafael Morales-Lage
Universitat Jaume I
Department of Economics
rmoraleslag@gmail.com

Aurelia Bengochea-Morancho
Universitat Jaume I
Department of Economics
bengoche@uji.es

Inmaculada Martínez-Zarzoso
Georg-August University of Göttingen
Universitat Jaume I
Department of Economics & IEI
martinei@uji.es

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Abstract

This paper applies the stochastic formulation of the IPAT model for analysing the determinants of CO_2 emissions in the 28 countries of the European Union (EU) from 1971 to 2012. We apply different methodologies in order to fit the best model: a model with cross-static and time effects and dynamic models to solve some problems related to the structure of the data. The best model is estimated using the Generalized Method of Moments (GMM). As far as the population is concerned, the whole set of countries have a unitary elasticity with respect to carbon dioxide emissions, similar to the elasticity related to GDP per capita and energy intensity. However, we find different effects in CO_2 emissions, depending on the group of countries considered. For the subset of EU-15 the influence of population, industry and energy use is lower than the influence shown by these factors in the 13 countries belonging to Central and Eastern Europe.

Keywords: IPAT equation, STIRPAT model, CO_2 emissions, European Union

JEL classification: Q43, Q48, Q53

The determinants of CO_2 emissions: evidence from European countries

Rafael Morales-Lage. Universitat Jaume I. 12080 Castellón, Spain. E-mail: rmoraleslag@gmail.com.

*Aurelia Bengochea-Morancho. Department of Economics. Universitat Jaume I. E-mail: bengoche@uji.es. Tel: 0034964728590. Fax: 0034964728591.

Inmaculada Martínez-Zarzoso. Department of Economics and Center for Statistics Georg-August Universitaet Goettingen (Platz der Goettinger Sieben 3 Goettingen 37073 Germany. Tel: 0049551399770. Fax:0049551398173) and Department of Economics and Instituto de Economía Internacional Universitat Jaume I, 12080 Castellón, Spain. E-mail: martinei@uji.es.

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*corresponding author

1. Introduction

Economic activity can satisfy a variety of needs. The more needs are met, higher the standard of living and higher the level of welfare. However human activity don't carry out only positive effects, but also produces negative externalities, particularly in the environment. Since the industrial revolution, the production systems intensive in energy use, coming from coal and fossil fuels, have led to an increase in pollution and environmental degradation. There is a clear upward trend in the greenhouse gases (GHG) emissions in all countries, developed and developing countries, as shown in Figure 1.

[Figure 1]

One of the consequences of this GHG increase is the climate change. Several studies have been conducted on the evolution of the temperature in the planet Earth. As shown in Figure 2, there is a moderate but constant and global raising in the temperature that evidences a climate change.

[Figure 2]

The 5th report of the Intergovernment Panel on Climate Change (IPCC), published in 2014, points out that the last three decades have registered the highest annual average temperature in the history of the humand kind. Global temperature of the earth and the oceans has raised 0.85ºC. Furthermore, there has been more extreme atmospheric phenomena with negative consequences in different areas: ice retreat in the glaciers, sea level rise and extreme drought and floods, among others phenomena.

The GHG emissions, such as carbon dioxide (CO_2), methane (CH_4) and nitrogen oxides (NOx) are mainly a result of the use of coal and oil combustion processes. According to the IPCC, the GHG are responsible of the climate change because there is a direct relationship between the atmosfheric concentration of GHG and the raise in average global temperature. The concentration of CO_2 in the atmosphere has increased by 35% between 1750 and 2005; that of CH_4 more than twice; and NOx by 18%. This increase is mainly due to the use of fossil fuels and in a lesser extent to changes in land use. Carbon dioxide is the most important anthropogenic GHG; these emissions have increased around 80% between 1970 and 2004. The main sectors responsible for CO_2 emissions are energy supply, industry and transport, because they use fossil fuels in their activities.

It is important to identify and quantify the factors influencing the raising of anthropogenic emissions in order to improve the efficiency of environmental policies affecting those factors that cause a higher amount of emissions. We can identify the main economic activities which determine the levels of CO_2 in the atmosphere but it is more difficult to identify the contribution of specific factors influencing these emissions.

This study examines this contribution by applying an econometric model, widely used in previous works such as the IPAT model, suggested by Ehrlich and Holdren (1971) to quantify the influence of population, affluence and technology in CO_2 emissions. The study updates the paper published by Martínez-Zarzoso *et al*. (2007) on European countries. The sample embrasses all present UE members from 1971 to 2012. The paper is structured as follows: section 2 provides a literature review on this subject; section 3 sets out the data and empirical model applied in this investigation; section 4 highlights the main resuls and section five concludes.

2. Literature review

Since the Rio Summit in 1992 and the Kyoto Protocol in 1997, several policies have been designed to curb global CO_2 emissions. In order to take action properly and to implement effective measures againts climate change, a lot of studies have been conducted examining the effect of several factors. Most of the studies are based on IPAT model proposed by Ehrlich and Holdren (1971) where environmental impact is related to population, affluence and technology. For instance, the effect of population has been investigated by Birdsall (1992), Daily and Ehrlich (1992), Dietz and Rosa (1997), Cramer (1998), Martínez-Zarzoso et. al. (2007). The impact of economic growth was the aim of the works of Selden and Song (1994), Grossman and Krueger (1995), Suri and Chapman (1998), Bengochea *et al*. (2000), Tisdell (2001), Paudel *et al.* (2006). Technological change was adressed by Boserup (1981) and Pasche (2002).

Dietz and Rosa (1997) formulate a stochastic version of the IPAT equation named STIRPAT, which has been applied in several empirical studies such as York *et al.* (2003) to verify whether the elasticity between population and emissions is unitary or not. One of the first empirical studies that attempt to model the effect of demographic variables on the pollution was conducted by Cramer (1998) and Cramer and Cheney (2000). These authors studied the behaviour of some gases emissions related to population growth in California and found some positive relationship with environmental impacts, such as ROG (reactive organic gases), CO, NOx and none with SOx and ozone.

More recent studies have introduced other variables in the model detailing more precisely the influence of the demographic pressure on climate change. Squalli (2009) distinguishes between foreign-born residents and USA-born residents for gauging the influence of immigration on local emissions of CO_2, NO_2, SO_2 and particulate matter. He considers 200 counties and concludes that there is no evidence that the composition of the population determine different levels of pollution.

Iwata and Okada (2014) analyze the relationship between population and the level of urbanization with GHG emissions in 119 countries and conclude that both variables affect positively in a proportional way the emissions of CO_2, CH_4 and NO_2. Moreover, they check the effect of the Kyoto Protocol on GHG emissions and outline a reduction of nitrogen oxides but nule reduction on carbon dioxide and methane.

Lin *et al*. (2009) investigate the relationship between population, urbanization and atmospheric pollution in China between 1978 and 2006. They conclude that population is the main factor influencing CO_2 emissions, according to the Malthusian thesis, and also the level of urbanization plays a significant role because the immigration flows internally generated in recent years within the process of industrial growth in this country. In fact, it is expected this process will continue leading to a significant increase of population residing in urban areas with an exponential increase in energy demand.

Liddle (2013) also pays attention to the degree of urbanization related with energy consumption for private transport, as an indicator of the level of emissions in different cities placed in developed and developing countries. The sample reffers to years 1990, 1995 and 2001. He find a negative relationship between the above variables, but to a greater extent in developing countries.

Marcotullio *et al*. (2014) analyse data referred to 1153 cities in 40 European countries in order to confirm the importance of urbanization, the demographic concentration and the raising of temperatures in the level of emissions.

Squalli (2010) uses a set of demographic data to identify factors influencing different GHG: total population, share of foreign people, population under 18, proportion of population aged between 18 and 64 years and the percentage of population living in urban areas compared to the total size of households. He concludes that most demographic variables are not significant to explain emissions except the total population which exhibits an elasticity close to unit. In the same vein, Liddle and Lung (2010) conducted a study focusing on the population age structure . They conclude that, apart from the positive relationship between total population and emissions, the increase of young people between 20 and 34 increases environmental impact due to the higher activity of this people, while the cohort between 50-64 and 65-79 cause a decrease due to their lower activity. In addition, the study shows that the cohort aged 35-49 have a negative influence on the environmental impact because, according to the authors, they live in larger homes with more consumption of energy. Finally they found a positive correlation between urban population and GHG emissions.

Hou *et al*. (2015) relate the population and the degree of urbanization along with other variables within the STIRPAT framework. They focus on different policy measures implemented in Xinjiang (China) for curbing CO_2 emissions between 2000 and 2010. As a result, they find population and the degree of urbanization affect the emission levels. Table 1 summarises the characteristics of some studies within the STIRPAT framework. The list is made in alphabetical order of authors.

Other studies address the problem of environmental degradation from a broader perspective. For example, Borghesi and Vercelli (2003) connect this phenomenon with the process of economic globalization occurred since the II World War and identify four mechanisms causing deterioration: the technological revolution, since every technological change has brought more pressure on the environment; the economic growth with more industrial activity; the demographic growth with a higher demand on natural resources; and finally, a cultural dimension related with the consumerist spirit of modern society.

Selden and Song (1994) introduced the idea of the existence of an Environmental Kuznets Curve (EKC), therefore the relationship between emissions and income exhibits an inverted U-shaped. There are several reasons for this phenomenon. The main justification is that environment is considered a normal good, so an increase in income leads to an increase in demand (Beckerman, 1992, Pasche, 2002). In turn, Grossman and Krueger (1995) justified the reduction of negative effects on the environment when income increases through three effects:

- The export of pollution. There is a relocation of polluting industries, coming from developed countries to less developed ones with weak environmental regulation (the pollution heaven effect). In that sense, Suri and Chapman (1998) believe that environmental regulation in developed countries encourages the transfer of polluting activities to less developed countries with less efficient use of energy and, therefore more polluted.

- Structural change or composition effect. As far as industrial economies became more developed, they became terciary economies based on the service sector with fewer polluting activities.

- Technological change. The most developed countries can invest in research and to implement production processes environmentally friendly. From this point of view Pasche (2002) believes that in the long term, with the possibility of technological change, environmental damage should not be a limit to growth.

The EKC hypothesis has been tested in several studies with different results. Aldy (2005) holds that the existence of an EKC is due to the relocation of polluting production into poorer countries with less environmental regulation and also to the improvement in the energy use within better production systems. Also Lozano and Gutierrez (2008) conclude that production growth can produce reasonable reductions in GHG emissions, according to the underlying EKC hypotesis. More recent studies have confirmed the existence of EKC curve as Baycan (2013) who analyzes several pollutants in a set of EU countries and finds evidence of the EKC in the EU15 countries and for the group of 25 countries after the 2007 enlargement, but not for the countries that have joined the EU later.

The EKC hypothesis is not without critizism. Kelly (2003) criticizes the EKC model since it ignores the changes in pollution control costs because pollution abatement when income increases does not offset increase in emissions due to the acceleration of productive activity (scale effect). Tisdell (2001) believes that the model does not take into account the cumulative factor of pollution (carrying capacity) nor the existence of irreversibility points, nor the waste absorption capacity of nature (resilience) and cannot justify the existence of the inflexion peak from which emissions will be reduced. Apart from these issues, some authors question the validity of the results obtained. For instance, Borghesi and Vercelli (2003) argue that studies based on local emissions give acceptable results but with global emissions, the results are not as expected, therefore the initial hypothesis has to be relaxed. In the same vein, Roca *et al*. (2001) recognize that developed countries have reduced their emissions but the studies were conducted at local level and have only take into account the affluence factor, thereby simplifying the model in exces without identifying the true causes of the relationship between the improvement of environment and income. Therefore, they argue the model has to be extended with the introduction of additional variables since for every contaminant and each country, the explanatory variables may vary depending on the different economic structure and the cultural and geographical conditions.

Archibald, et. al. (2009) check water pollution from 25 countries of Central and Eastern Europe; they confirm the existence of EKC for environmental impacts locally controllable. Carson (2010) outlines that, so far, studies show evidence of EKC with local gas emissions such as SO_2, while most studies reject their existence with global gases such as CO_2. He also states that income increases are the major cause of environmental deterioration in the world.

Angulo-Guerrero (2008), like Carson (2010), says that in any case the relationship between economic growth and environmental improvement is mechanical, therefore environmental policies are needed to make economic growth compatible with the environment conservation. In addition, he made critizism on all arguments supporting the existence of EKC: the effect composition does not play the same rol in all countries; the relocation of activities does not involves the reduction of pollution in global terms; the positive effect of technological progress is not sufficient to compensate the scale effect and also can bring changes in the composition of the economy of the countries who difficult the reduction of environmental impact; finally, there are not studies that could stated categorically that environmental goods are luxury (thus, an increase in income immediately leads to a greater demand for these goods inducing a positive effect on the preservation of the environment).

[Table 1]

3. Empirical Model and Data

3.1. The Model

Ehrlich and Holdren (1971) suggested an analytical framework to measure the environmental impact determinants. The formulation, known as the IPAT equation, relates environmental impact (I) with the population (P), affluence (A) and the technology causing environmental damage (T). This relationship arises from the analysis of different factors that influence polluting emissions:

- Population (P): the greater the population, the greater emissions.
- Scale Effect (A): the activity of the richest countries involves a greater amount of emissions.
- Technological effect (T): caused by the intensity of energy use.

$$I = P \cdot A \cdot T \qquad (1)$$

The IPAT approach is a tool that analyzes the environmental impacts in a general way, not just a tool for measuring GHG emissions. As shown in Table 1, the IPAT formulation has been widely used over the past years with different variables representing the environmental impact. Within the field of GHG emissions, Waggoner and Ausubel (2002) proposed a first variant of the IPAT equation, called ImPACT, where consumption of energy was added as a explanatory variable (C). This formulation coincides with the so-called Kaya identity (1990, 1991) formulated as follows:

$$CO_2 = P \cdot \frac{GDP}{P} \cdot \frac{Energy}{GDP} \cdot \frac{CO_2}{Energy} \qquad (2)$$

A variant of the above formulation can be done by eliminating the variable "population" in the model. Thus, Roca and Alcántara (2001) interpret the identity of Kaya to measure the influence of energy intensity (energy/GDP) and carbonisation index (CO_2/energy) regarding to emission intensity (CO2/GDP), leading to the following relationship:

$$\frac{CO_2}{GDP} = \frac{Energy}{GDP} \cdot \frac{CO_2}{Energy} \qquad (3)$$

The variable “energy” can be dropped out from the initial identity, leading to the following relationship which allows to study the influence of GDP per capita and the emissions intensity on emissions per capita:

$$\frac{CO_2}{P} = \frac{GDP}{P} \cdot \frac{CO_2}{GDP} \quad (4)$$

Kaya's approach is flexible and easy to use to facilitate the analysis of the relative influence of several factors in the level of emissions and their temporal variations. In fact, it is the basis on which calculations, projections and design scenarios are made by the IPCC. However, this approach is clearly limited being, like the IPAT equation and their different approaches, a multiplicative identity that assume proportionality in the effects of explanatory factors, ceteris paribus.

Dietz and Rosa (1994) claimed the IPAT formulation is purely conceptual and can not test hypotheses about the individual impact of each factor. In addition, the assumption of proportional effect on the environment of all factors considered in the model limits the possibility of reliable econometric estimations. Based on the initial equation of Ehrlich and Holdren (1971), Dietz and Rosa (1997) formulated a stochastic version of the IPAT equation that solves these problems. These authors designed their model with the term STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology). Equation 5 shows the specification of the model:

$$I_i = \alpha \cdot P_i^{\beta} \cdot A_i^{\gamma} \cdot T_i^{\delta} \cdot e_i \quad (5)$$

I, P, A and T are the variables previously defined α, β, γ, and δ are parameters to be estimated and *e* represents the error term.

In this paper we use the STIRPAT model as theoretical and analytical framework. Population (P) is measured by the number of inhabitants living in each country under study. The variable A is measured by gross domestic product per capita. Technology (T) is measured by the percentage of industrial activity in total production and also by the energy intensity.

3.2. The data

We have estimated the STIRPAT model formulated by Dietz and Rosa (1997) for 28 European countries along the period 1971 - 2012. The countries under study are the 15 EU member countries in 1995, plus the 13 countries who have joined the EU later. Except Cyprus and Malta, all countries in the last group have followed a process of transition from a planned economy to a market economy. The data are gathered from the International Energy Agency, except for the energy use which is taken from the World Development Indicators (WDI) published by the World Bank[1]. In the dataset, some data of Croatia, Estonia, Lithuania, Latvia and Slovenia are missing in the first years of the period, so we estimate the model with an unbalanced panel.

The model has been estimated in logarithmic form to facilitate the estimation of transversal and temporal effects. In addition, this formulation allows to interpret the coefficients of explanatory variables as elasticities, that means, the percentage increase in emissions corresponding to a 1% increase in the explanatory variable (York *et al.*, 2003). Our empirical model is as follows:

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1 http://data.worldbank.org/data-catalog/world-development-indicators

$$lnI_{it} = \alpha_i + \beta \ln P_{it} + \gamma \, lnA_{it} + \delta \ln T_{it} + \Psi_i + \Phi_t + e_{it} \quad (6)$$

The subscript i refers to the countries and t refers to different years of panel data. I_{it} is the amount of CO2 emissions for each country and year measured in tonnes; P_{it} is the total population; A_{it} is GDP per capita expressed in PPP and measured in constant dollars of the year 2005. T_{it} is measured by two variables: the percentage of industrial added value in relation to total output (GDP) and energy intensity, calculated by primary energy use divided by GDP and expressed in kg CO2/$ 1000. Furthermore, δi and Φt capture the fixed effects of countries and time. Finally, e_{it} is the error term. The effects of time (Φt) representing the unobservable variables common to countries that vary over time can be interpreted within the context of decomposition analyses, as the effects emissions have on technological progress over time in each country (Stern 2002).

4. Results

Equation 6 has been estimated first for the whole sample of selected countries using different methods. The results are shown in Table 2. The first column corresponds to ordinary least squares (OLS) estimation. The second one presents the results obtained considering fixed effects by country and year (FE). The third column shows the results of generalized least squares estimation with random effects (RE); White correction has been applied to have robust estimation of the variance-covariance matrix in the presence of heterocedasticity. The result of the Wald test leads us to reject the null hypothesis of non-significance of individual effects, therefore we cannot accept a common intercept consistent for all countries (as OLS estimation assumes) since each country has a different starting point. To elucidate wether the random effects fits better than the fixed effects model, we apply the Hausman test. The fixed effects approach gives a different value for every individual effects observed in the sample. The random effects approach assumes individual effects to be uncorrelated with other regressors, leading to an inconsistent model due to the lack of omitted variables. The Hausman test checks the orthogonality of random effects with the regressors. Under the null hypothesis of no correlation, both models are consistent but the fixed effect model is inefficient, while the alternative assumes the fixed effects model to be consistent but not the random effects model. The results of the Hausman test leads us to reject the null hypothesis, therefore the fixed effects model is efficient and consistent.

[Table 2]

All coefficients in the FE model are significant. The signs are as expected for GDP and population since an increase in population, in the GDP per capita or in the energy intensity implies an increase in the country's total CO_2 emissions. However, the negative sign of the variable *T* is contrary to expectations, maybe for the distortion caused by the lack of data in the series. The rest of the findings are similar to those obtained by Martínez-Zarzoso *et al*. (2007). When looking at the correlation matrix (Table 3), the set of variables don't exhibits collinearity problems between population and GDP per capita. The fixed effects model can have the problem induced by the non-stationary series, according to the closed value to 1 of the coefficient ρ (0.83) leading to spurious relations. We have applied the test of Levin *et al*. (2002) and Im et al. (2003) for both models, one with intercept and another one with intercept and trend. The first test assumes a common structure for all AR series, while the second one allows different AR coefficients for each serie. The results are shown in Table 4.

[Table 3]

[Table 4]

We find that variables have unitary roots in levels and we reject the existence of unitary roots when taking first differences. This fact indicates the presence of first order autocorrelation among the variables. To deal with this matter, we can take first differences and estimate then by OLS, solving this way the problem because the transformed variables are stationary series with much lower correlation. The results shown in the fourth column of Table 2 exhibit positive and significant coefficients except for the variable *T*.

Finally, we estimate a dynamic model for panel data to consider that current emissions levels depend on past ones. We apply the GMM method on the variables in first differences and we add as a explanatory variable the dependent variable lagged. Exogenous variables and the dependent variable lagged two periods are taken as instruments. The results show the weight of industry and the dependent variable lagged not to be significant. The population has a positive sign with an elasticity close to unit, as well as the GDP per capita and energy intensity.

Figure 3 shows the fixed effects for the whole set of countries. We cannot observe the existence of any trend over time. Fixed effects for every country are shown in Table 5. We can observe significant differences in the starting point of CO_2 emissions as a consequence of differences in the economic situation of countries analyzed in this panel:

countries belonging to EU15 have mostly negative values whereas last accession countries have mostly positive values. Notably the case of Lithuania as an outlier.

[Figure 3]

[Table 5]

In order to improve the estimation, we have made two subsamples according to the EU accession date. Thus, we estimate the model separately for EU-15 countries and for the group of 13 countries who joined the EU later. The results are shown in Tables 6 and 7.
For the first subsample (Table 6), in the dynamic model, the population is not significant. This result may be consistent with the evolution of population in the EU15 countries, with a stagnant vegetative growth in the last years, therefore being irrelevant as an explanatory factor of CO_2 emissions. Opposite, GDP and energy use are significant, with an elasticity close to unit in the case of GDP (0.98) and higher than one in the case of energy intensity (1.4).
For the other subset of countries (Table 7) we get different results. The coefficients of explanatory variables are positive and significant. The population shows an elasticity of 0.97, similar to that of GDP (0.89), while that of energy efficiency is 0.87. The weight of the industry has less influence (elasticity is 0.1). These findings differ from those obtained in our previous work (Martínez-Zarzoso *et al*., 2007) since the sample have been enlarged with more countries and more years and most countries have experienced relevant transformations along the last decade, particularly new accession countries.
The current results are similar to those obtained in other studies, such as Cole and Neumayer (2004), who estimate the elasticity of the population to be close to 1 and Shi

(2003), in the sense that population in developing countries have higher influence on CO2 emissions with respect to developed countries.

[Table 6]

[Table 7]

Figure 4 shows the fixed effects for both subsamples of countries. The graphic does not exhibit a clear trend or different behaviour among countries, except in the eighties when the second subset of countries were in the transition process from a planned economy to a free market economy and were most polluting countries than those of the EU15.

[Figure 4]

5. Conclusions

This study presents an analysis of the determinants of CO_2 emissions in Europe during the period 1971-2012, updating the results of previous work made by Martínez-Zarzoso *et al*. (2007). Instead of assuming implicitly an unitary elasticity between emissions and population, taking per capita emissions as dependent variable, we use the theoretical framework formulated by Dietz and Rosa (1997), in which population is treated as independent variable. Other covariates are GDP per capita (measured in constant 2005 dollars and expressed in PPP), industrial value added (in 2000 constant dollars); the energy consumption in the transport sector (in TOE) and the percentage of nuclear power and alternative energies with respect to the total power used.

We have used panel data econometrics and the model has been estimated by ordinary least squares method (OLS), fixed effects (FE) and random effects (RE). After checking for the non-stationarity of the series, we take first differences in the variables and estimate a dynamic model by using the GMM method.

The results show for the whole set of countries a unitary elasticity of emissions with respect to population, similar to the elasticty related to GDP per capita and energy intensity. This fact illustrates the importance the use of energy has on pollution and indicates the direction to be followed by public authorities when adopting environmental policies and meet the targets set by the EU for 2020. In this sense, it is very convenient to have the improvement of energy efficiency among the goals of Europe 20-20-20 strategy.

We have found population has different effects in CO_2 emissions, depending on the group of countries considered. Within the set of the EU15 countries, population does not exert an increasing pressure on CO_2 emissions due to its stagnantion along last years. In contrast, for the other 13 countries belonging to Central and Eastern Europe, the elasticity emissions-population is close to 1. For this group of countries the industry exhibits significant and direct influence on pollution.

As far as transition countries are concerned, it is worth to note the unitary value of population elasticity, which corroborates the Malthusian thesis, and the greater influence of industrial production and energy use on pollution as a consequency, most likely, of the productive inefficiency of these countries coming from a planned economy.

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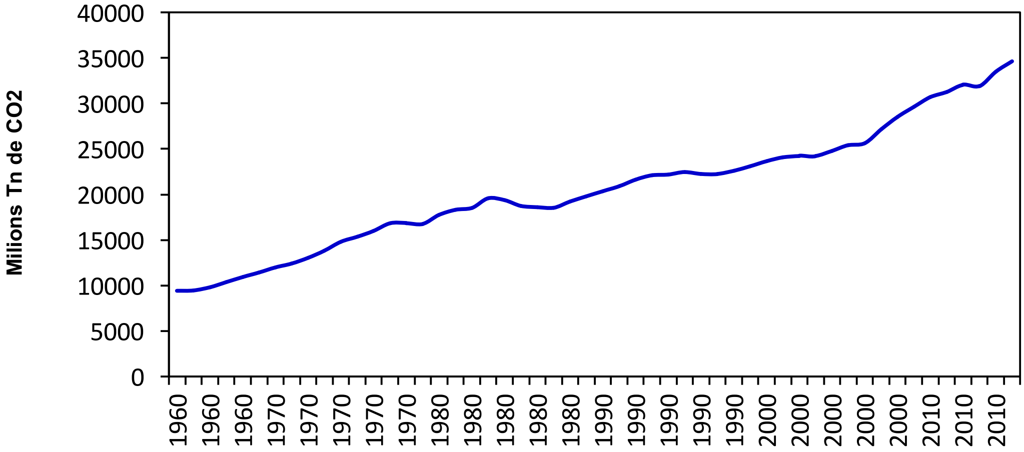
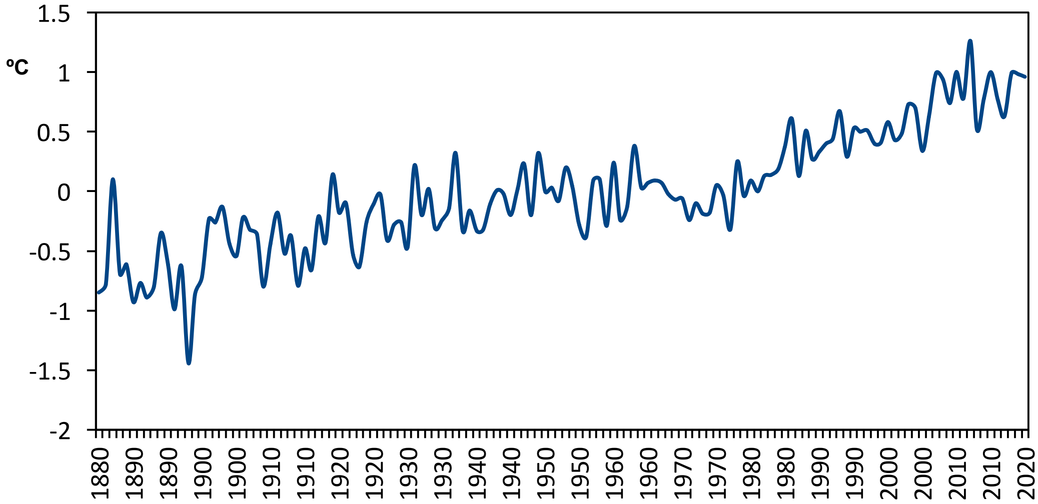
Figures and tables

Figure 1: Evolution of CO_2 emissions on 1990 basis



Source: Own data from World Development Indicators

Figure 2: Evolution of the Earth's temperature



Source: Own elaboration based on data from the Goddard Institute for Space Studies (GISS). Data are expressed as the mean variation of temperatures between 1951 and 1980.

Figure 3: Fixed effects for the whole set of countries

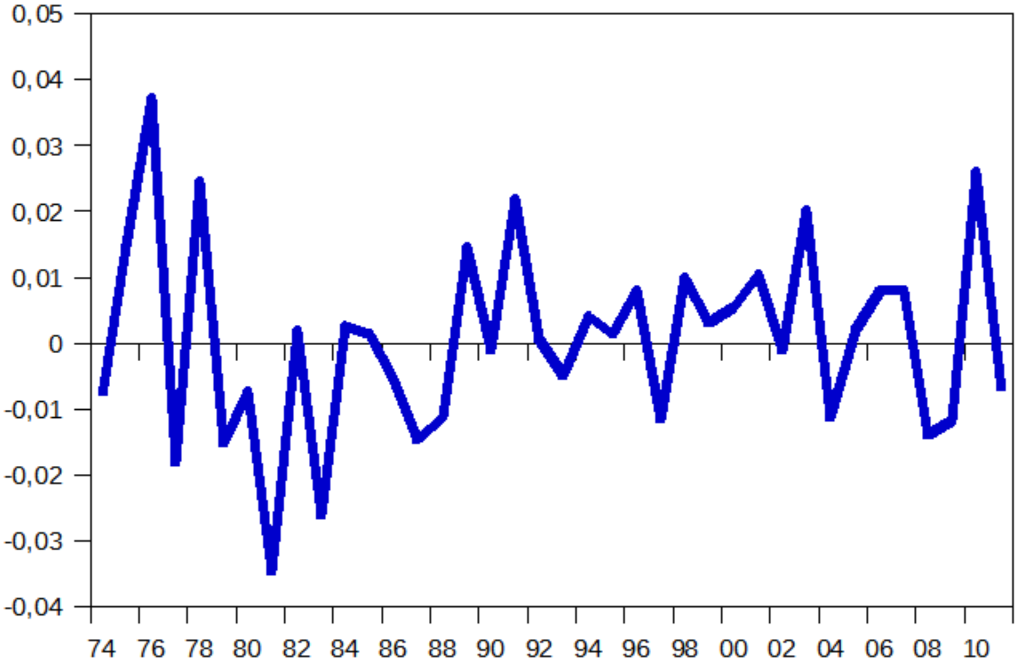


Figure 4: Fixed effects for EU15 countries and later accession countries

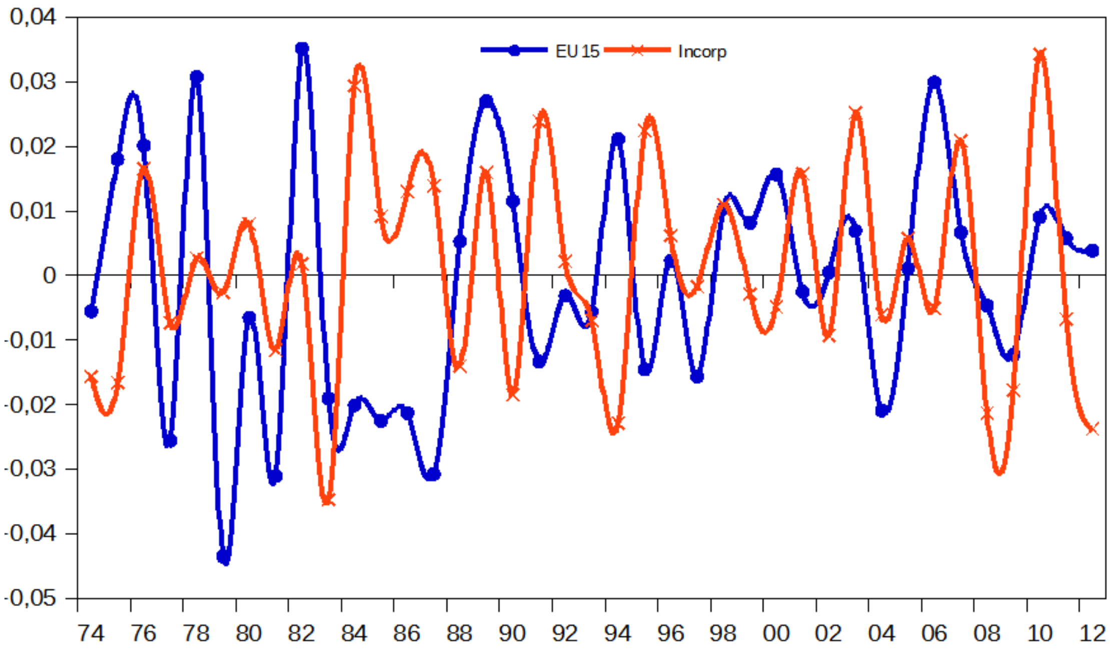


Table 1: A summary of studies within the STIRPAT framework

Authors	Period	Countries	Dependent variable	Independent variables	Estimation
Hou *et al*. (2015)	1958-2010	Xinjiang (China)	CO_2	GDP per capita, Population, energy use intensity, added value over GDP ratio, coal energy consumption over total fossil ratio, no agricultural population over total de population ratio	Descriptive and Ridge regression
Iwata and Okada (2014)	1990-2005	119	CO_2, CH_4, N_2O and HCFs-PFCs-SF6	Population, urbanization, GDP per capita, energy use intensity, % manufacturing added value	OLS, FE, RE and GMM
Lin *et al*. (2009)	1978-2006	China	Indicator of gases emitted in energy consumption	Population, urbanitzation, GDP per capita, energy intensity, industrialization	Ridge regression
Liddle (2013)	1971-2007	31OECD+ 56nonOCDE	CO_2 transport	Household electricity consumption, GDP per capita, % household energy consumption total consumption, urban population	Cointegration
Liddle and Lung (2010)	1960-2005	17 countries	CO_2 and energy consumption	GDP per capita, population, % population within 20-34, 35-49, 50-64, 65-79, % urban population, % household energy consumption, industrial energy consumption , % no fossil energy use, Km of rails/Km of roads.	OLS, FE
Lozano and Gutierrez (2008)	1990-2004	28	GHG	Population, GDP	Non parametric frontier
Marcotullio et al. (2014)	2000	40	CO_2 in urban zones	Urban population, Income, population density, population growth ratio, local climate indicator	OLS
Martínez-Zarzoso *et al*. (2007)	1975-1999	23	CO_2	Population, GDP per capita PPP, % % industry over total, energy use intensity	OLS, FE, RE, GMM
Squalli (2009)	2000	USA (157-400 counties)	CO_2, NO_2, PM and SO_2	Native population, foreign population, % foreigners over total population, income per capita, % employees in services and manufacturing sector	OLS, robust regression and quantile regression
Squalli (2010)	2000	USA	CO_2, NO_2, PM and SO_2	Population, GDP/capita PPP, % services over total , % manufacturing over total, urbanization, average household size, % population de under 18, % population 18-64 , coal consumption	robust regression and quantile regression

Source: Own elaboration

Table 2: Determinants of CO_2 emissions for all countries

Variable	OLS	FE	RE	First differences	GMM(DPD)
Constant	-9.65 (-20.6)***	-	-13.14 (-26.67)***	-	-
Ln P	0.97 (186.1)***	1.23 (18.9)***	0.95 (33.9)***	1.03 (3.67)***	0.89 (1.98)**
LnA	0.82 (29.6)***	1.26 (53.1)***	0.97(43.9)***	1.01 (14.7)***	0.92 (8.12)***
LnT	0.11 (2.62)***	-0.10 (-4.1)***	0.16 (5.98)**	0.02 (0.40)	0.03 (0.4)
LnEI	0.70 (21.80)***	1.03 (30.1)***	1.13 (39.2)***	0.95 (20.0)***	0.997 (12.9)***
$LnCO_2(-1)$	-	-	-	-	0.19 (0.2)
Period effects	Yes	Yes	-	Yes	Yes
R^2	0.98	0.99	0.87	0.76	0.73
S.E.	0.23	0.06	0.08	0.03	0.04
Wald test $\chi^2(28)$		14149***		-	-
White Heteroc.	8.28***	-		-	-
T. Hausman $\chi^2(4)$	-	-	12.7**	-	-
$P(\varepsilon_{it} = \rho\varepsilon_{it-1}+\upsilon_{it})$	-	0.83 (40)***		-	-

, ** and * denotes significance at 1%, 5% and 10% respectively*

t-value with the White correction in brackets

Table 3: Correlation matrix

	L_CO2	L_POB	L_GDP	L_IND	L_EI
L_CO2	1	0.969	0.298	-0.138	0.0672
L_POB	0.969	1	0.162	-0.098	0.040
L_GDP	0.298	0.162	1	-0.499	-0.565
L_IND	-0.138	-0.098	-0.499	1	0.339
L_EI	0.067	0.040	-0.565	0.339	1

Table 4: Analysis of stationarity

Intercept/slope	$lnCO_2$	$\Delta lnCO_2$	lnP	ΔlnP	lnA	ΔlnA	lnT	ΔlnT	lnEI	ΔlnEI
Levin, Lin & Chu	-1.0	-9.59*	-9.4*	-4.2*	0.37	-11.7*	-1.8	-8.29*	-0.87	-11.6*
IM, Pesaran & Shin	4.6	-8.1*	0.6	-2.6*	4.6	-7.94*	0.83	-6.23*	1.31	-9.97
Núm Obsr	1029	1001	1029	1001	1029	1001	624	596	1029	1001

* Non stacionarity is accepted at 1% of significance level.

Table 5: Fixed effects for every country

Country	Effect	Country	Effect
Austria	-0.000538	Bulgaria	0.003801
Belgium	-0.002695	Croatia	0.000452
Denmark	-0.008793	Cyprus	0.002052
Finland	-0.005352	Czech Republic	-0.002941
France	-0.009930	Estonia	0.004427
Germany	0.001772	Hungary	-0.003907
Greece	-0.004583	Latvia	-0.001242
Ireland	-0.002233	Lithuania	0.040636
Italy	-0.002915	Malta	0.001662
Luxembourg	0.005014	Poland	0.001386
Netherlands	0.003226	Romania	0.002219
Portugal	-0.002442	Slovak Republic	-0.002595
Spain	-0.001493	Slovenia	-0.002351
Sweden	-0.014218	United Kingdom	0.001581

Table 6: Determinants of CO_2 emissions in EU-15 countries

Variable	OLS	FE	RE	First differences	GMM(DPD)
Constant	-7.01 (-2.16)**	-	-8.35 (-7.8)***	-	-
Ln P	0.95 (21.6)***	1.16 (7.6)***	0.93 (22.9)***	1.38 (3.85)***	0.69 (0.95)
LnA	0.90 (4.3)***	1.20 (11.8)***	0.63(13.2)***	1.07 (9.5)***	0.98 (5.2)***
LnT	-0.11 (-0.41)	-0.16 (-2.9)***	0.23 (4.23)**	-0.09 (-1.5)	-0.13 (-1.9)*
LnEI	0.24 (0.94)	0.96 (11.0)***	0.90 (14.0)***	1.28 (21.8)***	1.40 (7.7)***
$LnCO_2(-1)$	-	-	-	-	0.35 (1.2)
Period effects	Yes	Yes	-	Yes	Yes
R^2	0.97	0.99	0.64	0.75	0.66
S.E.	0.21	0.07	0.08	0.03	0.04
Wald test $\chi^2(15)$	-	3423***		-	-
White Heteroc.	5.21***			-	-
T. Hausman $\chi^2(4)$	-		14.99**	-	-
$\rho(\varepsilon_{it} = \rho\varepsilon_{it-1} + \upsilon_{it})$	-	0.88 (38)***		-	-

, ** and * denotes significance at 1%, 5% and 10% respectively*

t-value with the White correction in brackets

Table 7: Determinants of CO_2 emissions for recent EU members

Variable	OLS	FE	RE	First differences	GMM(DPD)
Constant	-15.53 (-8.0)***	-	-14.63 (-32.7)***	-	-
Ln P	0.99 (16.9)***	1.13 (20.8)***	1.01 (29.1)***	1.06 (4.2)***	0.97 (2.3)**
LnA	1.2 (8.6)***	1.08 (36.5)***	1.04(64.6)***	0.93 (15.1)***	0.89 (12.4)***
LnT	0.19 (1.3)	0.05 (1.8)*	0.09 (5.16)**	0.096 (3.1)***	0.10 (3.1)***
LnEI	1.05 (6.5)***	1.04 (31.1)***	1.12 (52.3)***	0.84 (9.1)***	0.87 (7.8)***
$LnCO_2(-1)$	-	-	-	-	0.10 (0.47)
Period effects	Yes	Yes	-	Yes	Yes
R^2	0.99	0.99	0.98	0.84	0.83
S.E.	0.18	0.04	0.04	0.03	0.04
Wald test $\chi^2(13)$	-	3350***		-	-
White Heteroc.	9.69***			-	-
T. Hausman $\chi^2(4)$	-		4.3***	-	-
$\rho(\varepsilon_{it} = \rho\varepsilon_{it-1} + \upsilon_{it})$	-	0.59 (12)***		-	-

, ** and * denotes significance at 1%, 5% and 10% respectively*
t-value with the White correction in brackets