MASTER THESIS

# An Empirical Analysis of the Augmented Environmental Kuznets Curve with Corruption and Inequality: Evidence from the US-States

**Milka Christina**

*Supervisor: Panagiotis Konstantinou*
*Assessors: Theodore Panagiotidis & Eftichios Sartzetakis*

UNIVERSITY OF MACEDONIA

Economic and Social Sciences

DEPARTMENT OF ECONOMICS

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Contact information:

Chistina Milka

christina.milka@gmail.com

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# 1. INTRODUCTION

The aim of this study is to investigate the impact of different measurements of corruption and inequality on environmental regulation. For this reason, two different models were used, one without corruption and one with corruption. These two theoretical models were tested using an augmented Environmental Kuznets Curve in a cross-state panel dataset.

The relationship between economic growth and environmental quality has been studied from different views. The Environmental Kuznets Curve (EKC) hypothesis states that pollution level increase when a country is developing and begin to degrease when income rising pass beyond a turning point. This has been studied by Grossman and Krueger (1992), who came up with the inverted-U curve relationship between per capita income and pollution. The latter was restated by Grossman and Krueger in 1995, when they explored that it arises in a more complex set of relationships that have not yet been identified. Other points of view noticed by Selden and Song (1994), Agras and Chapman (1998) and Hilton and Levinson (1998).

On the one hand, the empirical evidence of the EKC hypothesis usually concerns a limited number of air pollutants and some water pollutants which in general have only local effects. There are many pollutants for which evidence are not available. Moreover, there is a large number of empirical studies that have documented the existence of EKCs for specific pollutants such as sulfur dioxide ($SO_2$), nitrogen oxide ($NO_2$) and suspended particulate matter (SPM). In particular, the basic models estimated in the literature are linear polynomial models that include quadratic and cubic terms of per capita income as explanatory variables or log linear polynomial models that include log quadratic and log cubic terms of per capita income. One variable that is usually omitted in the EKC relationship is the energy price that has been studied by Brown et al (1996).

Another element we can use to evaluate the EKC is the international trade. The most frequently used trade variable is the ratio of the sum of exports and imports to income. This variable has been used by Mycoff and Roop (1994). Additional explanatory variables are investment shares, electricity tariffs, civil liberties, energy price, industrial price, population, land, rents, competition, natural resources, income inequality, democracy, poverty, education and corruption. Nevertheless, most of the studies reach the same conclusion, per capita income has the most significant effect on environmental.

This study will examine the effect of corruption on environmental quality. Corruption is concindered in the literature as affecting the total productivity of a country and furthermore the government's concern and reaction towards environmental quality (Chimely and Braden, Lopez and Mitra (2000)). EKC evidence suggests the corruption is a significant cause of environmental problems (exp in the forestry and the marine sector) in countries with higher per capita income. The effect of corruption on the environmental standards has been analyzed by Lopez and Mitra (2000), they have found that corruption is not likely to preclude the existence of EKC, under the cooperative (Nash) and the non-cooperative (Stackelberg) assumptions. Moreover, they show that the turning point of EKC at income and pollution was over the social optimum, Damania (1999), Fredriksson and Svensson (2003), Damania, Fredriksson and List (2003) and Pellegrini (2006).

The main aim of this study is to examine the interaction between corruption, per capita income and inequality, and to focus on the impact of the above mentioned variables on environmental regulation. In order to satisfy the aim of this research, this study was based on a recent paper of Barrett (1994) which shows that if firms are not mobile, jurisdictions still are motivated to use environmental policy a strategic way in order to increase the profit of the national firms in an international duopoly. A same approach was also followed by Spenser and Brander (1983). Moreover, two basic choice models were developed in which environmental regulation is determined endogenously and the agents' income heterogenous. These models are an extended approach of EKC. The utility gained by the agents depends on profits and environmental quality, which is measured by environmental regulation as a proxy for emissions. The main difference of these models is the presence or the absence of the variable "corruption".

The first model laid one without corruption variable and in this model the regulation is determined by a majority vote. In this situation an increase in income will be followed by an increase in the environmental standards. This because a high level of inequality implies agents is much less considered about firms profits and the result is an increase in environmental standards. This follows easily on median voter models will make use of the environmental regulator strategically in order to increase firms profits the reason is simple the utility gained from a cleaner environment will be a major factor in the decision that will be made.

The second model includes the “corruption” variable in which the environmental standard is chosen by a corrupt bureaucrat. The main goal is to achieve higher profits, so lower environmental standards equal higher profits. In this situation an increase in income inequality reduces the “free rider” problem and the environmental standards.

To investigate the empirical content of those two models we use data on environmental regulation, corruption, per capita income, inequality and population were used. Firstly, an econometric analysis shows the effect of inequality on the environmental regulation and secondly the impact of corruption on the environmental regulation. To do so, we make use of two different panel data techniques. The predictions of both models are confirmed for per capita $NO_2$ and $CO_2$ emissions using fixed effect estimations. For per capita $SO_2$ the predictions are confirmed only for the height adjustment of EKC, using fixed effect estimations. Using the dynamic estimator of Arellano-Bond the prediction can be confirmed only for per capita $CO_2$ emissions and not for of the models that have been estimated. For the other two emissions the predictions can be confirmed only for the height adjustment of EKC.

The rest of this thesis is organized as follows. Section 2 displays the literature overview. Section 3 presents the specification of the models. Section 4 presents the data gathered and Section 5 the methodology. Section 6 shows the empirical results and Section 7 summarizes the main conclusions.

# 2. LITERATURE OVERVIEW

In this section, we give an overview of the empirical methods used in estimation of the relationship between per capita income and pollution across countries and we focus to the econometric analysis used in every instance.

## *2.1 ECONOMIC BACKROUND*

The relationship between per capita gross domestic product (GDP) and a level of pollutants is usually referred to on The Environmental Kuznets Curve (EKC), Moomaw (1998). In particular, the EKC describes the relationship between per capita and indicators of environmental degradation. At low level of development, the levels of pollutants rise after increases in per capita income and in high level of development, the levels of pollutant degreases with increases in per capita income, too. These results give us the inverted U-shaped curve relating economic growth with environmental quality, hypotheses of Kuznets (1995). The EKC hypothesis was merged in work by Grossman and Krueger's (1991). Kuznets (1995) also showed that the relationship between per capita income and income inequality shows an inverted U-shaped curve. In order to interpret this, he assumed that when the per capita income increases, income inequality also increases at the begging and then starts declining after a turning point. To be more specific, the distribution of income becomes more unequal in early stages of income growth and then the distribution of income becomes more equal as economic growth continues. In order to support this, Kuznets used data for three industrial countries: United States, Germany and England.

There are several empirical works and many explanations about the inverted U-shaped relationship in the literature. A report by Word Bank (1992) explains that the inverted U-shaped curve exists because of positive income elasticity for environmental quality. This means that when per capita income raises the demand for cleaner environment rises too.

Panayotou (2003) suggests that there are three rationales for this inverted U-shape. The first is that the turning point for pollution results in communities which place grate value on the environment to be cleaner and the governments are trying to influence this, with industrial and non-industrial measures. The second rational is that, pollution increases at the first steps of the industrial procedure and then after the production's advance, industries will gain prominence causing the reduction of pollution. The third rationale is that when a country begins industrialization the scale effect will take place and that means an increase in pollution levels. Furthermore, firms switching to less polluting industries, results in composition effect, which levels the rate of pollution and leads firms to invest in pollution abatement equipment which reduces pollution. From the above mentioned rationales Panayotou (2003) gains out to the last one as the most significant.

Copeland and Taylor (2003) reach the conclusion that there are at least four possible explanations. The most important is threshold effects in abatement that delay the onset of policy and income growth gives stronger income driven policy changes, structural changes towards industries and increasing returns to abatement that decrease the cost of pollution control.

Moreover, Dinda (2004) considers the following factors: income elasticity of the environmental quality demand, scale, composition and technique effects, international trade, foreign direct investments, race to bottom hypothesis, international assistance, globalization, role of prices, market mechanism, role of economic agents, transition to market economy, regulations, information accessibility, a change from insufficient to sufficient investment in abatement activity, property rights.

Lieb (2003) identifies the following factors that could explain the EKC shape: Substitution between pollutants, demand for environmental quality, returns to scale in abatement, technological progress, structural change, migration of dirty industries, shocks, income distributions, irreversibility's. As we can see, many factors are common between Lieb (2003) and Dinda (2004)ofhem the most important to be: scale, compositions and technique effects and demand for environmental quality.

Several indicators have been proposed to measure the environmental quality of the environmental degradation (Cialani 2007). Some of them are: carbon dioxide, carbon monoxide, nitrogen oxide, sulfur dioxide, suspended particulate matter, lead, smog, chlorofluorocarbons, sewage, biological oxygen demand and some other chemicals released directly into the atmosphere, rivers or oceans. But there is little evidence that EKC holds for all these different indicators.

In their survey Friedl and Getzner (2003) report four types of indicators to measure the environmental quality: emissions per capita, emissions per gross domestic output or gross domestic product, ambient levels of pollutions and total emissions. Carbon dioxide and sulfur dioxide emissions per capita are the most frequently used indicators in cross-country studies.

Kelly (2003) examine the relationship between economic growth and environment using a stock externality model on EKC and shows that when income raises over the growth path both the marginal effect and the marginal cost of pollution control rise and that the emission-income curve has a negative effect. Also, they examine how the relationship between income and environment reacts according to their different measures of environment.

Having increased information about ecological problems, the regulation is usually introduced, which forces the economy to make a transition to cleaner production processes. That is the explanation given by Smulders and Bretdchger (2000) about the EKC. Brock and Taylor (2004) developed the Green Solow model which is a combination of EKC and the Solow model. The Green Solow model is an augmented model with an abatement technology and shows that the curve is a result of the interplay between technological progress, convergence properties of neoclassical model and natural rate of regeneration. The technological progress can also be found in the Kindergarten Rule model of Brock and Taylor (2003). The Kindergarten rule indicates implementation of zero emission technologies in finite time or asymptotically. Thus, this model is a new prediction path of environmental quality to pollutant characteristics. The model is based on the role of technological progress to determine the diminishing returns to capital formation and to the abatement, with main purpose to improve the environment situation. The authors found that when the demand for a clean environment rises income does not follow a specific path. More specifically, the differences in geography, resource endowments or institutions have impact on productivity levels across countries, which lead to the Environmental Catch-Up hypothesis. This means that a poor country has worse environmental quality than a wealthy country even though they had the same initial levels of environmental quality. The authors found the uncover relationship between income and pollution like EKC, but essentially their results are different from the standard EKC. Therefore, economies can cause transitions to activate abatement at different income and have different pollution levels.

Also, Lieb (2004) in his model uses stock and flow pollutants. The flow pollutant causes immediate damages and the stock pollutant causes future damages. Lied obtained different results, such as the fact that the flow pollutant exists in low level of income and the stock pollutant exists in high level of income. Therefore he found different income levels at the turning point for different economies.

Chimely and Braden (2005) tried to find out how differences in total factor productivity (such as cultural values, corruption, violence, sabotage relative power of legal unions etc.) affect the quality of the environment. They develop a theoretical model where different total factor productivities produce a U-shape relationship between environment and income in cross-section countries, even though there is a monotonic dynamic path of environment across countries in its steady state. They also show that when the total factor productivity increases the environmental quality is better.

In developing countries the corruption and lobbying are very important for the governments' social welfare consideration. Lopes and Mitra (2000) suggests that government institutions in developing countries are more corrupted than in developed countries. They examine the impact of corruption and rent-seeking behavior by the government in relation to environmental quality and growth. They examine cases of cooperative and non-cooperative interaction between the government and private firms. They showed that, in both cases corruption induces the existence of an inverted U-shape EKC. In their model, high level of corruption indicates that the deviation from the social optimum is higher.

Barreto (2000) in his paper used a simple neoclassical model where corruption is an endogenous result of competition between a public agent and a private agent and suggests that if a paying bribe is acceptable by a firm, then the firm will pay a bribe. Also, he claims that corruption always has implication for income redistribution. Moreover, corrupt governments in environment with low economic growth usually display levels of corruption that persist over time. Mauro (2002) said that corruption is fount to lower investments and to reduce economic growth. Additionally, countries which are wealthy tent to have lower degree of corruption.

Leitao (2010) examined the impact of corruption in the relationship between sulfur emissions and income, with different degrees of corruptions and different levels of development. He found that a country with high degree of corruption has high per capita income, uses different income-pollution paths across countries due to corruption. The author used nonlinear transformations of nonstationary regressions in panel data estimation. He confirmed the existence of an inverted U-shape relationship between per capita sulfur emissions and income.

He, Makdissi and Wodon (2007) in their work, elaborate two public choice models to analyze the impact of corruption and inequality on environmental regulation. In the first model without the corruption variable, regulation is determined by majority vote, and leads to the result that higher inequality gives better environmental quality. In the second model in which corruption variable is included, the environmental standard is chosen by a corrupt bureaucrat, and higher degree of corruptions leads to decrease the quality of the environment. The above mentioned models where tested using a cross-country panel dataset. The authors confirmed the existence of an inverted U-shape relationship for both sulfur dioxide and carbon dioxide emissions, for the nitrogen dioxide emissions and they found the height adjustment of EKC but they did not foundthe inverted U-shape.

Monotonic and non-monotonic curves represent the relationship between income and pollution. Monotonic curves can be either income decrease with pollution decease or increase. Non-monotonic curves can be either inverted U-shaped or N-shaped curves. In this case, there are more complex patterns. The different patterns discovered in empirical research depended on the types of pollutants used and the models that have been investigated for their estimation. Four different theoretical arguments for an inverted U-shape curve for emissions have been represented by Selden and Song (1994), which are: positive income elasticities for environmental quality structural changes in production and consumption, increasing information on environmental consequences of economic activities, international trade in combination with open political systems. Pezzey (1989) and Opschoor (1990) have insisted that inverted U-shape relationships are not significant in the long run. They suggested N-shape curve relationships between income and pollutants.

## *2.2 ECONOMETRIC BACKROUND*

Stern (2004) argues that the criticism for the econometric aspect of the EKC falls into four categories: heteroskedasticity, omitted variables bias, cointegration and simultaneity. He presents that many surveys in EKC have an econometric misspecification. Lieb (2003) for the same issue says that there are six categories: simultaneity bias, the forms of other functions, time trend, multicollinearities, homogeneity tests and lagged effects. He supports that simultaneity may impair all the results, the forms of other functions may fit better with the data, the time trend may cause problems, there may be problems of multicollinearity in the regression and homogeneity may cause problem in the coefficients slope in some countries.

A literature review shows that in order to obtain a U-curve shape relationship between the pollution and per capita income its necessary to use quadratic and cubic per capita income terms. Aslanidis (2009) in his paper says that most the literature material on EKC is statistically weak with some exceptions. The reason for this is that there are linear polynomial models with quadratic terms of per capita income. Polynomial models, says Dinda (2004) are unable to provide the underlying causes of EKC. Simultaneity is the cause that polynomial model should be avoided (Hung and Shaw, 2002). This happens, because income and environmental quality are endogenous variables and the results are biased and inconsistent.

Aslanidis and Xepapadeas (2006) explore the idea of regime switching as new mythological approach in their analysis of the relationship between income and emissions. Their assumption explains that when some threshold is passed, the economy should move smoothly to another regime, with the relationship between income and emissions to be different among the old and the new regime. They used panel data for 48 States of the USA from 1929 to 1994. Moreover, for their study they used sulfur dioxide and nitrogen oxide emissions at state level. The idea of EKC confirmed only for sulfur dioxide emissions. Specifically, in their static smooth regression model, they found a robust smooth inverse V-shaped relationship between sulfur dioxide emissions and income.

There are studies on panel data analysis of the EKC that are using random, fixed and pooled effects. Aslanidis (2009) claims that panel data studies is underlying the assumption of homogeneity of income effects between the countries. This is very important because not all countries have the same relationship between per capita income and per capita emissions. This result is very important in the case of comparison between developed and developing countries. Grossman and Krueger (1991) first developed a study with random effect data across 42 countries for sulfur dioxide, 19 countries for dark matter and 19 countries for suspended particles. Their results for sulfur dioxide and dark matter follow N-shaped curve and for suspended particles followed inverted U-shaped EKC.

Seldon and Song (2003) confirmed the traditional EKCs analysis using a panel data analysis with cross section for fixed and random effects. The relationship between GDP and environmental degradation for 149 countries from 1960 to 1990 where tested from Shafic (1994) using panel data analysis for different environmental degradations. The EKC hypothesis is confirmed only for sulfur dioxide and SPM. Tucker (1995) confirmed the EKC hypothesis for 137 countries for 1971 to 1992 using also a panel data analysis. Furthermore, Moomaw and Unruch (1997) examine the relationship between carbon dioxide emissions and GDP for 16 countries for the period 1950 to 1992. The results of this study confirm the EKC hypothesis but with an inverted V-shaped curve. Moreover, Lantz and Feng (2006) examine the EKC hypothesis using a five-region panel dataset in Canada for 1970 to 2000. They use for explanatory variables per capita income, population and technology and for the pollutions indicator they use carbon dioxide. Their results show that per capita income and carbon dioxide emissions are not related, but when population or technology are included there is a U-shape relationship between per capita income and carbon dioxide emissions.

Cole et al. (1997) use a cross-section analysis to examine the traditional EKCs analyses. They used data for OECD countries from 1970 to 1992. For pollution indicators they used sulfur dioxide, nitrogen oxide, SPM, carbon dioxide, methane, municipal waste CFCs and halos. They confirm the EKC hypothesis only for the local air pollutants.

Another way, to explore the relationship between per capita income and environmental quality is time series regressions. In these cases, there is often a problem with spurious results, because the variables are non-stationary. Also, the unit root tests shows that these variables are integrated, Aslanidis (2009).

Friedl and Getzner (2003) examine the relationship between economic development and carbon dioxide emission for Austria from 1960 to 1999. They also used for explanatory variables GDP, imports and share of the tertiary. There results have shown N-shaped relationship between income and pollution. Furthermore, Soytas et al. (2007) explored the impact of energy consumption and output on carbon dioxide emission in the United States for 1960 to 2004. Except from GDP they used labor and gross fixed capital formation as explanatory variables. They used a new technique known as Toda-Yamamoto to test the Granger causality. In their study they did not confirm the EKC hypothesis. Ang (2008), tested the dynamic relationships between energy consumption, emissions and output using cointegration and error-correction models for France from 1960 to 2000. Their causality results confirm the EKC hypothesis. Additionally, Annichiarico et all. (2009) explored the relationship between economic growth and carbon dioxide emissions for Italy from 1981 to 2003. They used techniques like contegration, rolling regression and error-correction models. They found significant results according to EKC hypothesis.

Agras and Chapman (1998) analyze the dynamic approach of EKC hypothesis. They tried to investigate the relationship between carbon dioxide emissions and income and also the relationship between energy and income. In their dynamic approach they used also as trade variables the ratio of imports and exports of all manufactured goods. They found that the long-run income is not the most relevant indicator of environmental quality and energy demand. Furthermore, they showed that trade in manufactures goods has an important structural effect on per capita energy use.

In summary, the EKC literature shows that when per capita income raises then the different measurements of environmental quality increases at the first and after a turning point decreases. This is known as inverted U-shaped curve. Additionally, there are studies that have shown that the relationship between corruption and environmental quality follows the same mode with the relationship between income and environmental degradation.

As mentioned before, in this study, two models were used. One without taking into consideration the “corruption” indicator, which follows the classical approach of EKC hypothesis, and one augmented EKC model with an index of corruption. This research attempts to investigate if there is an inverted U-shape curve between corruption and emissions.

# 3. SPECIFICATION OF THE MODEL

## *3.1 THE BASIC MODEL*

The model used in this study follows that Barrett's duopoly framework. This paper starts with the assumption that every firm's location is in a different country. Each firm produces $y^i$ units, where i indicate the country, emit a local pollutant $z^i$. We assume that the output come out from the two firms is not consumed in any of the two countries. This means that the benefit from the decrease in the environment standard in country i is an increase in the national firm's profit. The profit $\pi^i$ for the firm in country i is given by:

$$\pi^i = r^i\left(y^1, y^2\right) - c^i\left(y^i\right) - e^i\left(y^i, z^i\right) \qquad (1)$$

Here, the instrumental variables represent the firm's revenue in production cost and also its environmental costs. We assume that: $r_j^i<0$, $c_j^i>0$, $e_j^i\leq 0$ and ezyi≤0.

The county i is populated with $n^i$ agents who differ only by their income, which depends on their share of national firm. The share of agent k in the national firm's capital is denoted by $\psi_k^i$. The preferences of the agents are represented by this utility function:

$$u_k^i\left(\pi^i, z^i\right) = \psi_k^i \pi^i - \varphi\left(z^i\right) \qquad (2)$$

where $\varphi'(\bullet)>0$ and $\varphi''(\bullet)>0$.

This game has two stages. The first stage represents the selection of the environmental standard. There are two possibilities for the determination of this standard, namely a major vote and a standard chosen by a bureaucrat who may be corrupted by the firm's owners. The second stage is the stage where the firms choose their output. We have to find a backward solution in this game, so we first solve the second stage. The Cournot-Nash equilibrium is given by the solution of:

$$\max_{y^i} r^i\left(y^1, y^2\right) - c^i\left(y^i\right) - e^i\left(y^i, \overline{z}^i\right) \qquad \textit{for} \quad i = 1,2 \qquad (3)$$

We subscript i as a partial derivative to yi, subscript ii as a second order partial derivative and subscript ij as a cross partial derivative, the first and second order conditions are:

$$r_i^i - c_y^i - e_y^i = 0 \qquad for \quad i = 1,2 \tag{4}$$

$$r_{ii}^i - c_{yy}^i - e_{yy}^i < 0 \qquad for \quad i = 1,2 \tag{5}$$

If we want to have a stable equilibrium, we assume that $r_{ij}^i<0$ and that $\pi_{11}^1\pi_{22}^2-\pi_{12}^1\pi_{21}^2>0$.

### *3.2 ENVIRONMENTAL REGULATION WITHOUT CORRUPTION*

At the first stage of the game, we suppose that the environmental standard is fixed by the vote of the majority. We assume that each of the agents, who ones one or more interests in the national firm, has a motivation to lower environmental standard in towards to rise profits. Accordingly, the voters use environmental standard as a strategic variable. While making their choice, each of the agents acknowledges the reaction of the voter in the other country. The agent *k* chooses the environmental standard $z^i_k$ in country i by the solution of:

$$\max_{z_k^i} \psi_k^i \pi^i \left(y^1, y^2, z_k^i\right) - \varphi\left(z_k^i\right) \tag{6}$$

Subject to: $$r_i^i - c_y^i - e_y^i = 0, \quad r_j^i - c_y^i - e_y^i = 0$$

The maximization of the behavior of the agents involves:

$$\psi_k^i \left[ \pi_i^i \frac{\partial y^i}{\partial z^i} + \pi_j^i \frac{\partial y^j}{\partial y^i}\frac{\partial y^i}{\partial z^i} - e_z^i \right] - \varphi_z = 0 \tag{7}$$

The maximization of the profit implies $\pi_i^i=0$.In this section, we can use the median voter theorem which says that the Condorcet winner of the vote of the majority in this framework gives the choice of the median voter $M_i$. So, the environmental standard is given by:

$$\psi_{Mi}^{i}\left[\pi_{j}^{i}\frac{\partial y^{i}}{\partial y^{i}}\frac{\partial y^{i}}{\partial z^{i}}-e_{z}^{i}\right]-\varphi_{z}=0 \tag{8}$$

In this situation, we can show that the first stage of the game is synonymous to a situation where the median voters in every country choose the environmental standards by assuming the Cournot-Nash equilibrium at the second stage of the game. We assume that each of the agents, who ones one or more interests in the national firm has the same result of the game is synonymous to Barret (1994) the optimal level of pollution at the national level.

If we want to have a stable equilibrium we must anticipate that:

$$\frac{\partial^{2}u_{Mi}^{i}}{\partial y_{i}^{2}}\frac{\partial^{2}u_{Mi}^{i}}{\partial z^{2}}-\frac{\partial^{2}u_{Mi}^{i}}{\partial y_{i}\partial z}\frac{\partial^{2}u_{Mi}^{i}}{\partial z\partial y_{i}^{2}}>0 \tag{9}$$

And also that:

$$\frac{\partial^{2}u_{Mi}^{i}}{\partial y_{i}^{2}}\frac{\partial^{2}u_{Mj}^{j}}{\partial y_{i}\partial z}\frac{\partial^{2}u_{Mj}^{j}}{\partial z\partial y_{i}}+\frac{\partial^{2}u_{Mi}^{i}}{\partial y_{i}\partial y_{j}}\frac{\partial^{2}u_{Mj}^{j}}{\partial y_{j}\partial y_{i}}\frac{\partial^{2}u_{Mj}^{j}}{\partial z^{2}}-\frac{\partial^{2}u_{Mi}^{i}}{\partial y_{i}^{2}}\frac{\partial^{2}u_{Mj}^{j}}{\partial y_{j}^{2}}\frac{\partial^{2}u_{Mj}^{j}}{\partial z^{2}}>0 \tag{10}$$

The Nash equilibrium of the game ($z^1$, $z^2$, $y^1$, $y^2$) is defined by relationships (4) and (7) for i=1, 2.

Analysis of equation (7) reports that the median voter’s interest of firm’s profit correlated negative with the environmental standard.

### *3.3 ENVIRONMENTAL REGULATION WITH CORRUPT BUREAUCRATS*

In this section, we make the assumption that the environmental standard in every country is chosen by a bureaucrat who may be corrupted. When there is no corruption, the bureaucrat chose the level of the emissions in every country according to the results of the majority vote. When there is corruption, we suppose that an agent may pay a bride of $B=b^i\Delta^i$ to the bureaucrat in order to incite him to set a lower level of environmental standard. The price per unit of lower regulation is $b^i$ and $\Delta^i$ deputizes the difference between the real level of regulation and the level of without corruption bureaucrat would expect to choose.

We assume that the firms are not able to pay brides. Also, we assume, as in Damania (2002), that there is a probability $\theta_i$ that a well executed audit will be done, driving to a sanction for the bureaucrat and $S_i(\Delta^i)$ is a money-metric of the disutility of the sanction imposed, with $S_i'(\bullet)>0$ and $S_i''(\bullet)\geq 0$. Furthermore, we suppose that the bureaucrat is not risk averse, so that the bureaucrat can maximize the expected income and w is the income of the bureaucrat without corruption. The expected outcome from the corruption for the bureaucrat with corruption is:

$$EGC = w + b^i \Delta^i - \theta_i S_i(\Delta^i) - w \qquad (11)$$

The maximization of the behavior of the bureaucrat is:

$$\theta_i S_i'(\Delta^i) = b^i \qquad (12)$$

This means that if the marginal increase in expected disutility is lower than the marginal price of bride the bureaucrat receives, the bureaucrat increases the emissions level. Also, if the probability of detection decreases the level of emissions will be higher. Consequently, we expect to find a positive correlation between the emissions level and the corruption level and a negative correlation between the environmental regulation level and the level of corruption.

Solving the above relationship for $\Delta^i$, we have a function $\Delta_s^i(b^i)$ that it is a supply function of emissions, the emissions is an input of the firm in our model. The agent's objective function is:

$$\max_{\Delta_k^i} \psi_k^i \pi^i \left( y^1, y^2, \hat{z}^i + \Delta_k^i \right) - \varphi\left( \hat{z}^i + \Delta_k^i \right) - b^i \Delta_k^i \qquad (13)$$

Subject to: $r_i^i - c_y^i - e_y^i = 0, \quad r_j^i - c_y^i - e_y^i = 0$ The maximization of the agent and profit maximization of the firm shows:

$$\psi_k^i \left[ \pi_j^i \frac{\partial y^j}{\partial y^i} \frac{\partial y^i}{\partial z^i} - e_z^i \right] - \varphi_z - b^i = 0 \qquad (14)$$

In this case, the level of corruption can be a public good for the agents of the firms. Thus, the agents can wait for other shareholders to finance the corrupted bureaucrat. Consequently the level of corruption will be defined by the demand of the emissions or the lower regulations of the richest agent:

$$\psi_{\max}^i \left[ \pi_j^i \frac{\partial y^j}{\partial y^i} \frac{\partial y^i}{\partial z^i} - e_z^i \right] - \varphi_z - b^i = 0 \qquad (15)$$

From the above relationship a function $\Delta_d^i(b^i : \psi_{max}^i)$ that it is a demand function for emissions which is increasing in $\psi_{max}^i$. We suppose that the bureaucrat and the richest agent are price receivers so that the determination of the emission is shown by $\Delta_d^i(b^i : \psi_{max}^i) = \Delta_s^i(b^i)$. Also, we assume that the richest agent is still engaged in a strategic game.

Conclusive, the impact of income inequality is uncertain.

# 4. DATA

In this section, an unbalanced panel data on environmental emission, per capita income, income inequality and corruption of 51 States of America during 1983-2010 is used to test the predictions of this studies model. According to the literature, there are only two cross-country data series of the measurement of environmental policy stringency. Considering that the judgment on the quality of the subjective environmental regulation strictness index is based frequently on whether they can predict the actual pollution level in every country, we are going to estimate our models for a numbers of air pollution indicators.

Sulfur emissions ($SO_2$) data set, nitrogen dioxide ($NO_2$) and carbon dioxide ($CO_2$), are used taken from National Priorities Project Federal Priorities Database, which includes all the States of America from 1990 though 2007. Emissions are measured in million Metric Tons of Electric Power Industry Emissions.Similarly, total carbon dioxide emissions from fossil fuel combustion are the largest source of greenhouse gas emissions within a state. To be more specific ithis study makes use of per capita emissions, which are calculates as emissions/annual population. In this case, there are per capita sulfur emissions (so2a), per capita nitrogen dioxide (no2a) and per capita carbon dioxide (co2a). All of these dependent variables are measured in tons/person.

The sulfur emission is among the most commonly used indicators in air pollution and it has several effects on natural environment and human health. The pollutants with inverted U-shaped curves do not involve international externalities. Therefore, the country that emits the pollutant suffers the damage and has the incentive to reduce emissions. To the contrary, carbon dioxide involves international externalities and it is related to the use of energy. as a result, the relationship between carbon dioxide emissions and economic growth has useful implications for environmental policies.

For the independent variables, land variable from Wikipedia measured in squared kilometers ($km^2$) for all the States of America was used. Annual population data is taken from Bureau Economic Analysis. Annual population is expressed in thousands inhabitants. For income inequality the study uses Gini coefficient panel data for the States of America from State-level Gini Coefficients calculated by Census Bureau for 1980 to 1994. The income data is taken from Bureau Economic Analysis for 1980 to 2004 and it is the Gross Domestic Product (GDP) by State measured in millions of current dollars. Also, the variable population density was used which equals to the annual population/land and measured in person/ $km^2$.

The index of corruption is provided by the department of justice and to be more specific from official corruption by tracfed. Corruption is explained as the reception of payment for an illegal act or enriching oneself from the public purse. This study uses the variable official corruption total as a sum of fed law enforcement, fed procurement, fed program, fed other, local official corruption and unspecified official corruption. The measurements of convictions of the official corruption total are taken place in this study. The index ranges from 0 to 108. States that have corruption close to 0 means that they have low corruption.

In literature close to our choice for corruption, Jie He, Paul Makdissi and Quendin Wodon (2007) used as an index of corruption the data selected by Transparency International which covers different aspects of corruption such as the frequency of bride's paid, total value of brides paid and the damage to private business caused by corruption. Also, Leitao (2010) used the index of corruption provided by the International Country Risk Guide which has also been used by Damania, Fredriksson and List (2003) and Fredriksson and Syensson (2003). This kind of corruption is based on measures to which "high government officials are generally expected throughout lower levels of government" or to which "illegal payments are generally expected throughout lower levels of government".

## 5. METHODOLOGY

In order to find out the impact of corruption and the impact of inequality on the environmental regulation an “augmented Environmental Kuznets Curve model” was used. According to the literature the Environmental Kuznets Curve (EKC) hypothesis states that pollution level increase when a country is developing and begin to degrease when income rising pass beyond a turning point. This has been explored since Grossman and Krueger (1992), finding of an inverted-U curve relationship between per capita income and pollution, and restated by them in 1995.

For each of the emissions and for each of the corruption index, the following estimations were used:

(1) Environmental Kuznets Curve model:

$$E_{it} = \gamma_i + a_1 Y_{it} + a_2 Y_{it}^2 + a_3 Y_{it}^3 + a_4 Z_{it} + \varepsilon_{it} \quad (16)$$

(2) Environmental Kuznets Curve model augmented with inequality:

$$E_{it} = \gamma_i + a_1 Y_{it} + a_2 Y_{it}^2 + a_3 Y_{it}^3 + a_4 Z_{it} + \beta_1 GINI_{it} + \varepsilon_{it} \quad (17)$$

(3) Environmental Kuznets Curve model augmented with corruption index:

$$\begin{aligned} E_{it} &= \gamma_i + a_1 Y_{it} + a_2 Y_{it}^2 + a_3 Y_{it}^3 + a_4 Z_{it} + \beta_1 corrutpion_{it-1} \\ &+ \beta_2 corrutpion^2{}_{it-1} + \beta_3 corrutpion^3{}_{it-1} + \varepsilon_{it} \end{aligned} \quad (18)$$

(4) Environmental Kuznets Curve model slope-augmented with inequality and corruption index:

$$\begin{aligned} E_{it} &= \gamma_i + a_1 Y_{it} + a_2 Y_{it}^2 + a_3 Y_{it}^3 + a_4 Z_{it} + \beta_1 GINI_{it} + \delta_1 corrutpion_{it-1} \\ &+ \delta_2 corrutpion^2{}_{it-1} + \delta_3 corrutpion^3{}_{it-1} + \varepsilon_{it} \end{aligned} \quad (19)$$

(5) Environmental Kuznets Curve model slope-augmented with inequality and corruption index:

$$E_{it} = \gamma_i + a_1 Y_{it} + a_2 Y_{it}^2 + a_3 Y_{it}^3 + a_4 Z_{it} + \beta_1 GINI_{it} + \beta_2 GINI_{it} \times corrutpion_{it-1} + \beta_3 GINI_{it} \times corrutpion^2{}_{it-1} + \beta_4 GINI_{it} \times corrutpion^3{}_{it-1} + \varepsilon_{it} \quad (20)$$

(6) Environmental Kuznets Curve model with inequality, income and corruption index:

$$E_{it} = \gamma_i + a_1 Y_{it} + a_2 Y_{it}^2 + a_3 Y_{it}^3 + a_4 Z_{it} + {} + \delta_1 \left( GINI_i \times corruption_{it-1} \times Y_{it} \right) + \delta_2 \left( GINI_i \times corruption^2{}_{it-1} \times Y_{it} \right) + \delta_3 \left( GINI_i \times corruption^3{}_{it-1} \times Y_{it} \right) + \varepsilon_{it} \quad (21)$$

Where the subscript i denotes country (state) and the subscript t denotes year. The first relationship denotes the Environmental Kuznets Curve model where the emissions indicator model ($E_{it}$) is a function of per capita income, in this research annual GDP per capita ($Y_{it}$) and some other indicators ($Z_{it}$). In literature we have seen that if we want to obtain a U-curve shape relationship between the pollutions and per capita income we have to use quadratic and cubic per capita income terms.

The second relationship is the same with the first relationship with an augmented term of inequality the index $GINI_{it}$. We assume that the $GINI_{it}$, coefficient according to the model to be negative, because it shows a decrease in pollution when then inequality increases.

The third equation is Environmental Kuznets Curve model augmented with corruption index. To follow the inverted U-curve shape we use quadratic and cubic terms of index of corruption. In every case we use corruption index we use it with one lag, because we assume that previous period corruption affects the quality of the environment now. According to the theory we expect a positive coefficient, to show that when corruption increases, the emissions increase. The next equation is the same equation added with index $GINI_{it}$, with negative coefficient.

The other equation is Environmental Kuznets Curve model augmented with inequality and corruption index in the same with the second with a new term which is the multiplication between the index of corruption and the inequality. To follow the inverted U-curve shape we use quadratic and cubic terms of the index of corruption. According to the theory we expect that the $GINI_{it}$, coefficient according to the model to be negative and the coefficient of the multiplication to be positive. That means, when we have an increase in corruption and in inequality we have an increase in emissions.

The next relationship has only the term which is the multiplication between the index of corruption and the inequality. We use only this term to investigate if corruption and inequality directly affect the pollution and the per capita income. In this situation we expect a negative coefficient.

At the last relationship we use term which is the multiplication between income, index of corruption and inequality. In this case we expect multiplication to have positive coefficient. In every multiplication we use quadratic and cubic terms of the index of corruption to investigate the inverted U-shape affect.

Another approach to estimate the impact of corruption and inequality on the environmental regulation is the use Dynamic equations. To be more specific, we have taken following estimations:

(7) Dynamic Environmental Kuznets Curve model:

$$E_{it} = \gamma_i + \theta_0 E_{it-1} + a_1 Y_{it} + a_2 Y_{it}^2 + a_3 Y_{it}^3 + a_4 Z_{it} + \theta_1 Z_{it-1} + \varepsilon_{it} \qquad (22)$$

(8) Dynamic Environmental Kuznets Curve model augmented with inequality:

$$\begin{aligned} E_{it} = \gamma_i &+ \theta_0 E_{it-1} + a_1 Y_{it} + a_2 Y_{it}^2 + a_3 Y_{it}^3 + a_4 Z_{it} + \theta_1 Z_{it-1} \\ &+ \beta_1 GINI_{it} + \varepsilon_{it} \end{aligned} \qquad (23)$$

(9) Dynamic Environmental Kuznets Curve model augmented with inequality and corruption index:

$$
\begin{aligned}
E_{it} = &\gamma_i + \theta_0 E_{it-1} + a_1 Y_{it} + a_2 Y_{it}^2 + a_3 Y_{it}^3 + a_4 Z_{it} + \theta_1 Z_{it-1} \\
&+ \theta_2 corruption_{it-1} + \theta_3 corruption^2{}_{it-1} + \theta_4 corruption^3{}_{it-1} + \varepsilon_{it}
\end{aligned} \tag{24}
$$

(10) Dynamic Environmental Kuznets Curve model augmented with inequality and corruption index:

$$
\begin{aligned}
E_{it} = &\gamma_i + \theta_0 E_{it-1} + a_1 Y_{it} + a_2 Y_{it}^2 + a_3 Y_{it}^3 + a_4 Z_{it} + \theta_1 Z_{it-1} + \beta_1 GINI_{it} \\
&+ \theta_2 corruption_{it-1} + \theta_3 corruption^2{}_{it-1} + \theta_4 corruption^3{}_{it-1} + \varepsilon_{it}
\end{aligned} \tag{25}
$$

(11) Dynamic Environmental Kuznets Curve model augmented with inequality and corruption index:

$$
\begin{aligned}
E_{it} = &\gamma_i + \theta_0 E_{it-1} + a_1 Y_{it} + a_2 Y_{it}^2 + a_3 Y_{it}^3 + a_4 Z_{it} + \theta_1 Z_{it-1} + a_5 GINI_{it} \\
&+ \theta_2 \left(GINI \times corruption\right)_{it-1} + \theta_3 \left(GINI \times corruption^2\right)_{it-1} \\
&+ \theta_4 \left(GINI \times corruption^3\right)_{it-1} + \varepsilon_{it}
\end{aligned} \tag{26}
$$

(12) Dynamic Environmental Kuznets Curve model augmented inequality, corruption and income:

$$
\begin{aligned}
&E_{it} = \gamma_i + \theta_0 E_{it-1} + a_1 Y_{it} + a_2 Y_{it}^2 + a_3 Y_{it}^3 + a_4 Z_{it} + \theta_1 Z_{it-1} \\
&+\theta_2 \left(GINI \times corruption \times Y\right)_{it-1} + \theta_3 \left(GINI \times corruption^2 \times Y\right)_{it-1} \\
&+\theta_4 \left(GINI \times corruption^3 \times Y\right)_{it-1} + \varepsilon_{it}
\end{aligned} \tag{27}
$$

The main difference between dynamic and static equations is the use of the term that denotes the emissions with one lag and all the multiplications with corruption with one lag. To estimate all of the above equations, we use panel data techniques. Panel data is a dataset in which the behavior of the entities is observed across time. The first technique we use is Fixed Effects.

Fixed Effects analyze the impact of variable that vary over time. Fixed Effects explore the relationship between predictor and outcome variables within the entity. Its entity has its own individual characteristics that may or may not influence the predictor variable. When using Fixed Effects we assume that something within the individual may impact or bias the predictor or outcome variables and we need to control for this. This is the rationale behind the assumption of the correlation between entity's error term and predictor variables. Fixed Effects remove the effect of those time-invariant characteristics from the predictor variables so we can assess the predictors' net effect.

Another important assumption of the Fixes effects model is that those time-invariant characteristics are unique to the individual and should not be correlates with other individual characteristics. Each entity is different therefore the entity's error term and the constant should not be correlated with the others. One side effect of the features of Fixed Effects is that they cannot be used to investigate time-invariant caused of the dependent variables. Technically, time invariant characteristics of the individuals are perfectly collinear with the entity dummies. Substantively, Fixed Effects models are designed to study the causes of changes within an entity. A time invariant characteristic cannot cause such a change, because it is constant for each entity.

The equation for Fixed Effects models becomes:

$$Y_{it} = \beta_1 X_{it} + a_i + \varepsilon_{it} \tag{28}$$

Where

- $\alpha_i$ (i=1…n) is the unknown intercept for each entity
- $Y_{it}$ is the dependent variable where, i=entity and t=time
- $X_{it}$ is one independent variable
- $B_1$ is the coefficient for the independent variable
- $e_{it}$ is the error term

The xtscc procedure in Stata is the technique that has been used to estimate the Fixed Effects. The produces Driscoll and Kraay (1998) standard errors for coefficients estimated by pooled OLS/WLS or fixed-effects (within) regression. Depvar is the dependent variable and varlist is an (optional) list of explanatory variables. The error structure is assumed to be heteroskedastic, autocorrelated up to some lag, and possibly correlated between the groups (panels). These standard errors are robust to very general forms of cross-sectional and temporal dependence when the time dimension becomes large. However, because this nonparametric technique of estimating standard errors does not place any restrictions on the limiting behavior of the number of panels, the size of the cross-sectional dimension in finite samples does not constitute a constraint on feasibility - even if the number of panels is much larger than T. Nevertheless, because the estimator is based on an asymptotic theory one should be somewhat cautious with applying this estimator to panel datasets with a large number of groups that have only a short number of observations. This implementation of Driscoll and Kraay's covariance estimator, works for both, balanced and unbalanced panels, respectively. Furthermore, it is capable to handle missing values. We use this nonparametric technique which is not possible to estimate random effects.

The second technique we use is dynamic panel data. Consider the linear dynamic panel data specification given by:

$$Y_{it} = \sum_{j=1}^{p} \rho_j Y_{it-j} + X_{it}'\beta + \delta_i + \varepsilon_{it} \qquad (29)$$

First-differencing this specification eliminates the individual effect and produces an equation of the form:

$$\Delta Y_{it} = \sum_{j=1}^{p} \rho_j \Delta Y_{it-j} + \Delta X_{it}'\beta + \Delta\varepsilon_{it} \qquad (30)$$

which may be estimated using GMM techniques.

Efficient GMM estimation of this equation will typically employ a different number of instruments for each period, with the period-specific instruments corresponding to the different numbers of lagged dependent and predetermined variables available at a given period. Thus, along with any strictly exogenous variables, one may use period-specific sets of instruments corresponding to lagged values of the dependent and other predetermined variables.

Our main goal is to seek the “true” value of this parameter, $\theta_0$, or at least to find a reasonably close estimate. In order to apply GMM there should exist a (possibly vector-valued) function $g(Y,\theta)$ such that

$$m(\theta_0) \equiv \mathrm{E}\left[g\left(Y_t,\theta_0\right)\right] = 0 \qquad (32)$$

where, E denotes expectation, and $Y_t$ is just a generic observation, which are all assumed to be i.i.d. Moreover, function $m(\theta)$ must not be equal to zero for $\theta \neq \theta_0$, or otherwise parameter $\theta$ will not be identified. The basic idea behind GMM is to replace theoretical expected value E with its empirical analog-sample average:

$$\hat{m}(\theta) = \hat{\mathrm{E}}\left[g\left(Y_t,\theta\right)\right] \equiv \frac{1}{T}\sum_{t=1}^{T} g\left(Y_t,\theta\right) \qquad (33)$$

By the Law of Large Numbers, $\hat{m}(\theta) \approx m(\theta)$ for large values of $T$, so if we can find a number $\hat{\theta}$ such that $\hat{m}(\hat{\theta}) \approx 0$ then such number will be a reasonably good estimate for parameter $\theta_0$. So basically all we need to do is to search the parameter space $\Theta$ for a number $\theta$ which would minimize the distance between $\hat{m}(\theta)$ and zero. For a vector-valued function $\hat{m}$ the notion of distance can be defined in many different ways, and it actually turns out that the obvious Euclidian norm is not the best choice. Instead a new positive semi-definite “weighting” matrix $\hat{W}_T$ is often used which is used to define the norm as a quadratic form $\|\hat{m}\| = \hat{m}'\hat{W}_T\hat{m}$. Thus, the GMM estimator can be written as:

$$\hat{\theta} = \arg\min_{\theta\in\Theta} \left(\frac{1}{T}\sum_{t=1}^{T} g(Y_t,\theta)\right)' \hat{W}_T \left(\frac{1}{T}\sum_{t=1}^{T} g(Y_t,\theta)\right) \qquad (34)$$

Under suitable conditions this estimator is consistent, asymptotically normal, and with right choice of weighting matrix $\hat{W}_T$ asymptotically efficient.

Linear dynamic panel-data models include p lags of the dependent variable as covariates and contain unobserved panel-level effects, fixed or random. By construction, the unobserved panel-level effects are correlated with the lagged dependent variables, making standard estimators inconsistent. Arellano and Bond (1991) derived a consistent generalized method of moments (GMM) estimator for the parameters of this model. This estimator is designed for datasets with many panels and few periods, and it requires that there be no autocorrelation in the idiosyncratic errors.

This Arellano-Bond estimator's methodology has the following advantages:

- it allows to handle strictly exogenous and predetermined regressors, even if arbitrarily correlated with the unobserved effects.
- it yields robust estimates with respect to serial correlation and heteroskedasticity of errors.
- it does not require any assumption about the initial observations of the dependent variable.

The robustness of estimators is linked to the hypothetical cointegrating relations between the reference variables: in particular, such estimates can be obtained whether the cointegrating relation expressed by our particular model is significant (this implies a stationary error) or not (in this case the error must be integrated).

Robust statistics seeks to provide methods that emulate popular statistical methods, but which are not unduly affected by outliers or other small departures from model assumptions. In statistics, classical methods rely heavily on assumptions which are often not met in practice. In particular, it is often assumed that the data residuals are normally distributed, at least approximately, or that the central limit theorem can be relied on to produce normally distributed estimates. In order to quantify the robustness of a method, it is necessary to define some measures of robustness. Robust parametric statistics tends to rely on replacing the normal distribution in classical methods with the t-distribution with low degrees of freedom or with a mixture of two or more distributions.

We use robust standard errors which specify that the resulting standard errors are consistent with panel-specific autocorrelation and heteroskedasticity in one-step estimation.

The *xtabond* procedure in Stata automatically performs two of the validation tests defined by Arellano and Bond, the Sargan specification test and the lack of auto-correlation test. In particular, the first is based upon the assumption of lack of serial correlation (of the differenced error $\Delta u_{it}$). The second test, used to test lack of correlation of second order, provides a fundamental check for the consistency of estimators.

The Sargan test has a null hypothesis of "the instruments as a group are exogenous". Therefore, the higher the p-value of the Sargan statistic is the better. In robust estimation stata reports the Hansen J statistic instead of the Sargan with the same null hypothesis. The Arellano Bond test for autocorrelation has a null hypothesis of no autocorrelation and is applied to the differenced residuals. The test for AR (1) process in first differences usually rejects the null hypothesis.

In a GMM context, when there are more moment conditions than parameters to be estimated, a chi-square test can be used to test the over-identifying restrictions. The test statistic can be called the J statistic. In more detail: Say there are q moment conditions and p parameters to be estimated. Let the weighting matrix be the inverse of the asymptotic covariance matrix. Let T be the sample size. Then T times the minimized value of the objective function ($TJ_T(\ _T)$) is asymptotically distributed with a chi-square distribution with (q-p) degrees of freedom.

When the number of moment conditions is greater than the dimension of the parameter vector $\theta$, the model is said to be *over-identified*. Over-identification allows us to check whether the model's moment conditions match the data well or not.

Conceptually we can check whether $m(\theta)$ is sufficiently close to zero to suggest that the model fits the data well. The GMM method has then replaced the problem of solving the equation $m(\theta)=0$, which chooses $\theta$ to match the restrictions exactly, by a minimization calculation. The minimization can always be conducted even when no $\theta_0$ exists such that $m(\theta_0) = 0$. This is what J-test does. The J-test is also called a *test for over-identifying restrictions*.

Formally we consider two hypotheses:

- $H_0 : m\left(\theta_0\right) = 0$ (the model is "valid"), and
- $H_1 : m\left(\theta\right) \neq 0, \quad \forall \theta \in \Theta$ (the model is "invalid"; the data do not come close to meeting the restrictions)

Under hypothesis $H_0$, the following so-called J-statistic is asymptotically *chi-squared* with $k–l$ degrees of freedom. Define $J$ to be:

$$J \equiv T\left(\frac{1}{T}\sum_{t=1}^{T} g\left(Y_t, \hat{\theta}\right)\right)' \hat{W}_T \left(\frac{1}{T}\sum_{t=1}^{T} g\left(Y_t, \hat{\theta}\right)\right) \xrightarrow{d} x_{k-l}^2 \qquad (35)$$

under $H_0$, where $\hat{\theta}$ is the GMM estimator of the parameter $\theta_0$, $k$ is the number of moment conditions (dimension of vector $g$), and $l$ is the number of estimated parameters (dimension of vector $\theta$). Matrix $\hat{W}_T$ must converge in probability to $\Omega^{-1}$, the efficient weighting matrix (note that previously we only required that $W$ be proportional to $\Omega^{-1}$ for estimator to be efficient; however in order to conduct the J-test $W$ must be exactly equal to $\Omega^{-1}$, not simply proportional).

Under the alternative hypothesis $H_1$, the J-statistic is asymptotically unbounded:

$$J \xrightarrow{p} \infty \text{ under } H_1$$

To conduct the test we compute the value of $J$ from the data. It is a nonnegative number. We compare it with the 0.95 quantile of the $x^2_{k-l}$ distribution:

- $H_0$ is *rejected* at 95% confidence level if $J > q_{0.95}^{x_{k-l}^2}$
- $H_0$ cannot be rejected at 95% confidence level if $J < q_{0.95}^{x_{k-l}^2}$

Time dummies have been included in every estimation model and in every technique that has been used.

# 6. EMPIRICAL RESULTS

Tables and Figures are located in the Annex. Tables 1-3 present the fixed effect estimation results for the pollutions indicators. The columns tittles (1)-(5) and (8) report the estimation results based on the six EKC models proposed above.

According to the EKC literature there is a significant inverted U-shape form correlation between GDP and per capita $CO_2$ and $NO_2$ emissions. For $SO_2$ emissions we can see opposite significant coefficients with the literature. The estimated coefficients associated to population density have the expected results only for $CO_2$ emissions. For $SO_2$ and $NO_2$ the coefficients for the population density did not have the expected significance.

The inclusion of the variable GINI into the traditional EKC model, through linear participation in models (2), (4) and (5), multiplied with index of corruption in models (5) and (6) and multiplied with the index of corruption and per capita income in models (7) and (8) does not seems to affect the results of EKC. For per capita $CO_2$ emissions we obtain the expected significant negative coefficients for the variable GINI in models (2), (4) and (5). These results confirm the theoretical approach that has been discussed before in our first theoretical model. For per capita $SO_2$ and $NO_2$ emissions we obtain significant positive coefficients for the variable GINI in the same models.

The inclusion of the multiplicative term between GINI and the index of corruption, with the corruption index appearing in level, quadratic and cubic forms in model (5) tests the prediction of our second theoretical model. The results for per capita $CO_2$ and $NO_2$ emissions are not significant, but for per capita $SO_2$ emissions the results show statistically significant coefficients and indicated that the relationship between pollution and GINI does depend on the actual value of the index of corruption. In this point, the states have been organized into three different groups according to their corruption level: low corruption states, mean corruption states and high corruption states. Now the original multiplicative term between GINI and the index of corruption becomes the multiplication between GINI and the three dummy variables that indicate low, mean and high corruption states. This is the description of model (6). The results show significant and different coefficients only for the multiplication of GINI with the dummy which represents the low corruption level in states for per capita $CO_2$ and $NO_2$ emissions, and for per capita $SO_2$ emissions there are statistically significant coefficients for the three different multiplications. As GINI is multiplied in this model by three dummies that indicate whether or not a state belongs to low, mean or high corruption group, single GINI term cannot be included at the same time.

The inclusion of the multiplicative term between GINI, the index of corruption and per capita income with the corruption index appearing in level, quadratic and cubic forms in model (8), also tests prediction of our second theoretical model. The results for per capita $CO_2$ emissions are not significant, but for per capita $NO_2$ and $SO_2$ emissions the results show statistically significant coefficients and indicated that the relationship between pollution and GINI does depend on the actual value of the index of corruption and the actual value of per capita income. In this point, the original multiplicative term between GINI, the index of corruption and per capita income becomes the multiplication between GINI the three dummy variables that indicate low, mean and high corruption states and per capita income. This is the description of model (7). The results show significant and different coefficients only for the multiplication of GINI with the dummy which represents the low corruption level in states for per capita $CO_2$ and $NO_2$ emissions, and for per capita $SO_2$ emissions there are statistically significant coefficients for the three different multiplications, which are the same with the results of model (6). Also, in this model the single GINI term cannot be included at the same time.

Furthermore, the inclusion of the corruption index appearing in level, quadratic and cubic forms in model (3) tests the prediction of our second theoretical model. The estimation results for all three pollution indicators show statistically significant coefficients. It can be obtained that for per capita $SO_2$ and $NO_2$ emissions the existence of an inverted U-shape relationship according to the coefficients. In model (4) there is corruption index appearing in level, quadratic and cubic forms and GINI together. In this case, the estimation results for all three pollution indicators be evidence for statistically significant coefficients. That means that the co-existence of inequality and corruption will reduce $SO_2$ and $NO_2$ emissions but the opposite result can be found for the $CO_2$ emissions.

Corresponding results for model (8) for all three pollution cases are illustrated graphically in Figure 1-3. Firstly the simple EKC is estimated (the blue line) purged of the height-adjustment effect from GINI and corruption index in all the panels. The use of three different values of GINI: Low ($25^{th}$ percentile value of the sample), Mean ($50^{th}$ percentile value of the sample) and High ($75^{th}$ percentile value of the sample), help us to illustrate the height-reduction impact of GINI on EKC. Comparison with the three panels shows that the height-reduction effect of GINI on EKC increases with the GINI index. Also, in each panel there is a suggestion of the height-adjusted EKC caused by the same inequality level for the three different state groups of corruption level: Low ($25^{th}$ percentile value of the sample), Mean ($50^{th}$ percentile value of the sample) and High ($75^{th}$ percentile value of the sample). The three panels of per capita $SO_2$ and $NO_2$ emissions reveal the same results between the group differences, but for per capita $CO_2$ emissions there is a great difference between the group of high level of GINI among the other two groups. In the cases of per capita $SO_2$ and $NO_2$ emissions, it can be obtained, the theoretical prediction confirmation that the height-adjusted ECKs of the country group having the lowest corruption level are situated at the lowest position, for per capita $CO_2$ emissions the country group having the lowest corruption is situated at the highest position. This can be explained by the fact that $CO_2$ is a global pollution, trade-off between the negative damage suffered by people and the benefit obtained by the polluter is thus much more difficult to capture than in the local pollution cases of the other emissions. The mean corruption group for the three emissions is always between the other two levels, except for per capita $CO_2$ emissions for high level of GINI that the difference between the different levels of corruption cannot be obtained.

Moreover, Tables 4-6 present the dynamic estimation results using one step Arellano-Bond estimator for the pollutions indicators. According to the EKC literature there is a significant inverted U-shape form correlation between GDP and per capita $CO_2$ emissions. For $SO_2$ and $NO_2$ emissions we cannot see significant coefficients. The estimated coefficients associated to population density have the expected results only for $CO_2$ emissions. For $SO_2$ and $NO_2$ the coefficients for the population density did not have the expected significance. Also, for the emissions dependent variable it can be obtained that for per capita $SO_2$ and $NO_2$ all estimations for one lag emission are significant, the estimations for one lag per capita $CO_2$ emissions are not all significant.

For per capita $CO_2$ emissions we obtain the expected significant negative coefficients for the independent variable GINI in models (2) and (5). These results confirm the theoretical approach that has been discussed before in our first theoretical model. For the other two emissions there are positive significant coefficients for the variable GINI in models (2) and (5). For model (4) there are no significant results for the three emissions. In model (5) for per capita $CO_2$ emissions the multiplicative term between GINI and the index of corruption, with the corruption index appearing in level, quadratic and cubic forms with one lag are not significant. For the other two emissions the results are significant with the expected coefficients. The inclusion of multiplication between GINI and the three dummy variables that indicate low, mean and high corruption states with one lag, shown at model (6), for per capita $CO_2$ there are no significant results. For the other two emissions there negative significant results only for the interaction with the low level of corruption. In model (7) it can be obtained the same results with model (6) for per capita $NO_2$ and $SO_2$ emissions. For per capita $CO_2$ there is a negative significant coefficient for the multiplication of GINI, GDP and the mean level of corruption. In model (8) it can be taken the same results with model (5). For model models (6)-(8) the single GINI term cannot be included at the same time with the other indicators.

Furthermore, the inclusion of the corruption index appearing in level, quadratic and cubic forms with one lag in model (3) tests the prediction of our second theoretical model. For per capita $NO_2$ and $SO_2$ emissions there are significant results, but for $CO_2$ there are no significant results. In model (4) there is corruption index appearing in level, quadratic and cubic forms with one lag and GINI together. In this case, the estimation results for all three pollution indicators are the same with model (3). That means that the co-existence of inequality and corruption will reduce $SO_2$ and $NO_2$ emissions but the opposite result can be obtained for the $CO_2$ emissions.

Corresponding results for model (8) for all three pollution cases are illustrated graphically in Figure 4-6 for Arellano-Bond estimations. Firstly the simple EKC is estimated (the blue line) purged of the height-adjustment effect from GINI and corruption index in all the panels. The way the panels are made is the same with the panels of the fixed effect estimations. The three panels of per capita $SO_2$ and $NO_2$ emissions reveal the same results between the group differences, but for per capita $CO_2$ emissions there is a great difference between the group of high level of GINI among the other two groups. In the cases of per capita $SO_2$ emissions it can be obtained the theoretical prediction confirmation that the height-adjusted ECKs of the country group having the lowest corruption level are situated at the lowest position, for per capita $CO_2$ and $NO_2$ emissions the country group having the lowest corruption, the mean corruption and the high corruption are not situated clearly.

In all of the diagrams it can be obtained that the line for the emissions, without corruption or inequality has no linear representation and the line that describes the emission with corruption and inequality in different groups has a linear representation. This can be explained by the fact that the coefficients of the simple EKC are smaller than the coefficients in the augmented EKC with the multiplication of corruption and inequality.

Corresponding results for models (2)-(4) for all three pollution cases are illustrated graphically in Figure 7 for fixed effect estimations. In these figures, there are represented the relationship between GDP and emissions without interaction terms of corruptions and inequality. The main idea is to find out if there is an existence of ECK in those three models, which differ to the input of independent variables, as it had represented in the theoretical approach before. For all models we can see the existence of EKC accordingly with the shape of the lines. In the figure in the top there are the results for per capita $CO_2$ emissions. Model (4) which is the model in which is included the independent variables that describe corruption index and inequality is placed in the lowest point. That may happen because of the existence of these variables that reduce the effect of GDP on the level of emissions. Model (3) is in the middle of the representation of the three models and has the same slope movements with model (4). In this case, we can explain that the existence of corruption in this model is the main indicator that decreases the impact of GDP on the environmental emissions. For model (2), which is on the top at the representation of this diagram, we can also observe the existence of EKC shape. The results for per capita $SO_2$ and $NO_2$ are represented to the next figures for the same models. As we can see there is the existence of an inverted U-shape relationship according to the figures.

In Figure 8 there is the graphical illustration for models (2)-(4) for the relationship between GDP and per capita emissions estimates with Arellano-

Bond technique. It is obvious to understand that there is a cubic relationship between GDP and the three emissions. For the figure that represents the results for $SO_2$ it can be obtained that it follows the same way with the $CO_2$ estimated with fixed effects.

Corresponding results for models (3)-(4) for all three pollution cases are illustrated graphically in Figure 9 for fixed effect estimations. In these figures, there are represented the relationship between corruption and emissions. The main idea is to find out if there is an existence of ECK in those three models. For all models we can see that the EKC hypothesis is confirmed accordingly with the shape of the lines for the three per capita emissions. The same results can be obtained in Figure 10, which is the graphical illustration for models (3)-(4) for the relationship between corruption and per capita emissions estimates with Arellano-Bond technique.

# 7. CONCLUSION

In this thesis we aim to analyze the effect of corruption and inequality on environmental emissions. For that reason two theoretical modes (public choice models) are examined. The first model is the model without corruption and the second model is the model with corruption. In the case of the first model the environmental regulation is determined by a majority vote, where higher level of inequality leads to better environmental standards. In the model with corruption the environmental standard is chosen by a corrupt bureaucrat, where higher level of corruption will increase the level of emissions, because will reduce the quality of environmental regulation.

The models mentioned above, were tested using a cross-state panel dataset with two different techniques, in order to capture the potential adjustment in both height and curvature of augmented EKC that can be caused by inequality and corruption of each state. The empirical results of this study did not seem to support the EKC hypothesis for all the estimated models. The predictions of both models are confirmed for per capita $NO_2$ and $CO_2$ emissions using fixed effect estimations. That means that the inverted-U Shape hypothesis of the EKC is confirmed. For per capita $SO_2$ the predictions are confirmed only for the height adjustment of EKC. Using the dynamic estimator of Arellano-Bond the prediction can be confirmed only for per capita $CO_2$ emissions and not for of the models that have been estimated. For the other two emissions the predictions can be confirmed only for the height adjustment of EKC. For models (2)-(4) we have shown graphically the existence of the EKC hypothesis, for static and dynamic estimations, between GDP and per capita emissions. Also, the EKC hypothesis is confirmed in the relationship between corruption and per capita income.

# REFERENCES


Agras, J. and Chapman, D. (1998),"A Dynamic Approach to the Environmental Kuznets Curve Hypothesis", Ecological Economics, 28, 267-277.

Arrelano, M and Bond, S., (1991) "Some Tests of Specification for panel data: Monte Carlo Evidence and an application to employment equations", *Review of Economic Studies*:58:277-297

Aslanidis, N. and Xepapadeas, A. (2006),"Smooth Transition Pollution-Income Paths", Ecological Economics, 57, 182-189.

Aslanidis, N. (2009), "Environmental Kuznets Curves for Carbon Emissions: A Critical Survey",Working Paper No 51.

Barreto, R., 2000, "Endogenous Corruption in a Neoclassical Growth Model", The European Economic Review 44, 35-60.

Barrett, S (1994), "Strategic Environmental Policy and International Trade", Journal of Public Economics, 54, 325-338.

Brock, W. A. and M. S. Taylor, 2003, "The Kingdergarten Rule of Sustainable Growth", NBER Working Paper No. 9597.

Brock, W. A. and M. S. Taylor, 2004,"The Green Solow Model", NBER Working Paper No. 10557.

Chimeli, A. and J. Braden, 2005, "Total factor productivity and the environmental Kuznets curve", Journal of Environmental Economics and Management 49, 366-380.

Cialani, C. (2007),"Economic Growth and Environmental Quality: An Econometric and a Decomposition Analysis", Management of Environmental Quality: An International Journal, Vol. 18, No.5.

Cole, M.A. (2004),"Trade, the pollution haven hypothesis and the environmental Kuznets curve: examining the linkage", Ecological economics, 48, 71-81.

Cole, M.A. (2007),"Corruption, income and the environment: An empirical analysis", forthcoming in Ecological Economics.

Cole, M.A., A.J. Rayner and J.M. Bates (1997),"The environmental Kuznets curve: an empirical analysis", Environment and Development Economics, 2, 401-416.

Copeland, B. R. and M. S. Taylor, 2003, "Trade, Growth and the Environment", NBER Working Paper No. 9823.

Damania, R. (1999),"Political Competition, Rent Seeking and the Choice of Environmental Policy Instruments", Environmental and Resource Economics, 13, 415-433.

Damania, R. (2002),"Environmental Controls with Corrupt Bureacrats", Environment and Development Economics, 7, 407-427.

Damania, R., P.G. Fredriksson and J.A. List (2003),"Trade liberalization, corruption, and environmental policy formation: theory and evidence", Journal of Environmental Economics and Management, 46, 490-512.

De Bruyn, S.M., Van De Bergh, J.C.J.M. and Opschoor, J.B. (1998),"Economic Growth and Emissions: Reconsidering the Empirical Basis of Environmental Kuznets Curves", Ecological

Economics, 25, 161-175

Dinda, S., (2005),"A Theoretical Basis for the Environmental Kuznets Curve", Ecological Economics 53, 403-413.

Driscoll, J. C., and A. C. Kraay. (1998), "Consistent Covariance Matrix Estimation with Spatially Dependent Panel Data,. *Review of Economics and Statistics* 80: 549–560.

Feng, Q. and Lantz, V. (2006),"Assesing Income, Population, and Technology Impacts on CO2 Emissions in Canada: Where's the EKC? ", ecological economics, 57, 229-238.

Fredriksson, P.G. and J. Svensson, 2003,"Political instability, corruption and policy formation: the case of environmental policy", Journal of Public Economics 87, 1383-1405.

Friedl, B. and Getsner, M. (2003),"Determinants of CO2 Emissions in a Small Open Economy", Ecological Economics, 45, 133-148.

Grossman, G.M. and Krueger, A.B. (1995),"Economic Growth and the Environment", The Quarterly Journal of Economics, Vol. 110, No.2, 3533-377.

He, J., Makdissi, P. and Wodon, Q., (2007),"Corruption, Inequality, and Environmental Regulation", Working Paper.

Heil, M.T. and T. M. Selden, (2001),"Carbon emissions and economic development: future trajectories based on historical experience", Environment and Development Economics, 6, 63-83.

Hilton, F.G.H. and A. Levinson, 1998,"Factoring the Environmental Kuznets Curve: Evidence from Automotive Lead Emissions", Journal of Environmental Economics and Management 35, 126-141.

Kelly, D. L., 2003,"On environmental Kuznets curves arising from stock externalities", Journal of Economic Dynamics & Control 27, 1367-1390.

Kuznets, S. (1955),"Economic Growth and Income Inequality", The American Economic Review, Vol. 45, No.1, pp. 1-28.

Leitão, A. (2006),"Corruption and the Environmental Kuznets Curve: Empirical Evidence for Sulfur", (Preliminary Version).

Lieb, C. M, 2004,"The Environmental Kuznets Curve and Flow versus Stock Pollution: the Neglect of Future Damages", Environmental and Resource Economics 29, 483-506.

López, R. and S. Mitra, 2000,"Corruption, Pollution, and the Kuznets Environment Curve", Journal of Environmental Economics and Management 40, 137-150.

Mauro, P., 2002,"The Persistence of Corruption and Slow Economic Growth", IMF Working Paper 02/213.

Panayotou, T. (2003),"Economic Growth and the Environment", Spring Seminar of the United Nations Economic Commission for Europe, Geneva.

Pezzey, J.C.V. (1989),"Economic Analysis of Sustainable Growth and Sustainable Development", Environment Department, Working paper 15, World Bank.

Pellegrini, L. (2006),"Corruption, Democracy, and Environmental Policy: An Empirical Contribution to the Debate", Journal of Environment and Development, 15, 332-354.

Porter, M., J. Sachs and K. Schwab (2002),"The global competitiveness report 2001-2002", New-York: Oxford University Press.

Shafik, N. (1994),"Economic Development and Environmental Quality: An Econometric Analysis", Oxford Economic Papers, Vol. 46, 757-773.

Selden, T.L. and D. Song (1994),"Environmental Quality and Development: Is there a Kuznets curve for Air pollution emissions? ", Journal of Environmental and Management Economics, 27, 147-162.

Smulders, S. and L. Bretschger, 2000,"Explaining Environmental Kuznets Curves: How Pollution Induces Policy and New Technology", CentER discussion paper 2000-95.

Soytas, U., Sari, R. and Ewing, B.T. (2007) "Energy Consumption, Income, and Carbon Emissions in the United States", 62, 482-489.

Unruh, G.C. and Moomaw, W.R. (1998),"An Alternative Analysis of Apparent EKC-type Transitions", Ecological Economics, 25, 221-229.

World Bank (1992),"World Development Report 1992: Development and the Environment". Oxford University Press Inc., New York.

# ANNEX

## 1. TABLES

**Table 1. Per capita CO2 emission (kg/p) – Fixed effect**

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| | co2a | co2a | co2a | co2a | co2a | co2a | co2a | co2a |
| gdp | 0.0809$^{***}$ | 0.0773$^{***}$ | 0.0404$^{*}$ | 0.00223 | 0.0769$^{***}$ | 0.0806$^{***}$ | 0.0801$^{***}$ | 0.0805$^{***}$ |
| | (31.88) | (13.43) | (2.57) | (0.12) | (13.19) | (23.34) | (21.76) | (21.91) |
| gdp2 | -1.591$^{***}$ | -1.528$^{***}$ | -1.127$^{***}$ | -0.410 | -1.517$^{***}$ | -1.596$^{***}$ | -1.591$^{***}$ | -1.592$^{***}$ |
| | (-30.42) | (-10.73) | (-4.43) | (-1.30) | (-10.31) | (-25.42) | (-23.79) | (-20.12) |
| gdp3 | 7.354$^{***}$ | 7.216$^{***}$ | 6.335$^{***}$ | 2.698$^{\circ}$ | 7.189$^{***}$ | 7.454$^{***}$ | 7.432$^{***}$ | 7.479$^{***}$ |
| | (27.04) | (10.24) | (4.45) | (1.96) | (9.81) | (22.39) | (21.31) | (18.11) |
| popd | -0.00321$^{***}$ | -0.00225$^{**}$ | -0.0110 | -0.00644 | -0.00250$^{**}$ | -0.00274$^{***}$ | -0.00274$^{***}$ | -0.00314$^{*}$ |
| | (-3.95) | (-3.33) | (-1.29) | (-1.10) | (-2.81) | (-3.67) | (-3.78) | (-2.62) |
| gini | | -6.460 | | -22.68$^{**}$ | -6.753 | | | |
| | | (-1.39) | | (-2.97) | (-1.39) | | | |
| lc | | | -0.0317$^{*}$ | -0.0252$^{\circ}$ | | | | |
| | | | (-2.16) | (-1.99) | | | | |
| lc_2 | | | 0.000792$^{*}$ | 0.000617$^{\circ}$ | | | | |
| | | | (2.17) | (1.87) | | | | |
| lc_3 | | | -0.00000505$^{*}$ | -0.00000363$^{\circ}$ | | | | |
| | | | (-2.19) | (-1.73) | | | | |
| lg_c | | | | | -0.0607 | | | |
| | | | | | (-1.46) | | | |
| lg_c_2 | | | | | 0.00167 | | | |
| | | | | | (1.55) | | | |
| lg_c_3 | | | | | -0.0000105 | | | |
| | | | | | (-1.48) | | | |
| lg_c_low | | | | | | 0.648$^{**}$ | | |
| | | | | | | (2.69) | | |
| lg_c_mean | | | | | | -0.254 | | |
| | | | | | | (-0.81) | | |
| lg_c_high | | | | | | 0.111 | | |
| | | | | | | (0.53) | | |
| lggdp_c_low | | | | | | | 18.01$^{*}$ | |
| | | | | | | | (2.29) | |
| lggdp_c_mean | | | | | | | -0.279 | |
| | | | | | | | (-0.03) | |
| lggdp_c_high | | | | | | | 1.047 | |
| | | | | | | | (0.18) | |
| lg_c_gdp | | | | | | | | -0.757 |
| | | | | | | | | (-0.96) |
| lg_c_2_gdp | | | | | | | | 0.0183 |
| | | | | | | | | (0.94) |
| lg_c_3_gdp | | | | | | | | -0.000112 |
| | | | | | | | | (-0.92) |
| _cons | 0.849 | 3.999$^{\circ}$ | 11.27$^{**}$ | 26.24$^{***}$ | 4.338$^{*}$ | 1.064 | 1.218 | 1.234 |
| | (1.29) | (1.91) | (3.36) | (4.75) | (2.06) | (1.13) | (1.29) | (1.48) |
| *N* | 918 | 765 | 639 | 567 | 761 | 816 | 816 | 812 |
| $R^2$ | 0.2487 | 0.2494 | 0.2638 | 0.2753 | 0.2517 | 0.2649 | 0.2607 | 0.2570 |

*Robust t* statistics in parentheses $^{\circ}$ $p < 0.10$, $^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$

## Table 2. Per capita SO2 emission (kg/p) – Fixed effect

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| | so2a | so2a | so2a | so2a | so2a | so2a | so2a | so2a |
| gdp | -0.000227° | 0.000150 | -0.00144*** | -0.00103*** | 0.000172 | -0.000239° | -0.00019 | -0.000216 |
| | (-1.90) | (1.16) | (-5.32) | (-3.58) | (1.23) | (-1.79) | (-1.46) | (-1.46) |
| gdp2 | 0.00581** | -0.00384 | 0.0310*** | 0.0210*** | -0.00421° | 0.00536* | 0.00456* | 0.00467* |
| | (3.47) | (-1.73) | (5.86) | (3.60) | (-1.83) | (2.52) | (2.25) | (2.10) |
| gdp3 | -0.0261*** | 0.0189° | -0.161*** | -0.107*** | 0.0198° | -0.0234* | -0.0205* | -0.0223* |
| | (-3.53) | (1.78) | (-5.40) | (-3.72) | (1.81) | (-2.40) | (-2.22) | (-2.26) |
| popd | 0.000018* | 0.0000057 | 0.000146 | 0.0000504 | 0.0000164° | 0.0000161* | 0.000014° | 0.0000410 |
| | (2.46) | (0.98) | (1.42) | (1.41) | (1.96) | (2.11) | (1.81) | (3.22) |
| gini | | 0.542*** | | 0.378* | 0.538*** | | | |
| | | (9.12) | | (2.38) | (9.40) | | | |
| lc | | | 0.00109*** | 0.000885** | | | | |
| | | | (3.53) | (3.12) | | | | |
| lc_2 | | | -0.0000231*** | -0.000021*** | | | | |
| | | | (-4.42) | (-3.91) | | | | |
| lc_3 | | | 0.00000019*** | 0.00000012*** | | | | |
| | | | (4.50) | (3.75) | | | | |
| lg_c | | | | | 0.00194** | | | |
| | | | | | (3.12) | | | |
| lg_c_2 | | | | | -0.000047*** | | | |
| | | | | | (-3.79) | | | |
| lg_c_3 | | | | | 0.00000028*** | | | |
| | | | | | (3.87) | | | |
| lg_c_low | | | | | | -0.0207** | | |
| | | | | | | (-3.06) | | |
| lg_c_mean | | | | | | 0.0162** | | |
| | | | | | | (2.86) | | |
| lg_c_high | | | | | | 0.0106° | | |
| | | | | | | (1.70) | | |
| lggdp_c_low | | | | | | | -0.631** | |
| | | | | | | | (-2.99) | |
| ggdp_c_mean | | | | | | | 0.339** | |
| | | | | | | | (2.75) | |
| ggdp_c_high | | | | | | | 0.338* | |
| | | | | | | | (2.16) | |
| lg_c_gdp | | | | | | | | 0.0339** |
| | | | | | | | | (3.10) |
| lg_c_2_gdp | | | | | | | | -0.000677* |
| | | | | | | | | (-2.91) |
| lg_c_3_gdp | | | | | | | | 0.00000384 |
| | | | | | | | | (2.78) |
| _cons | 0.0493° | -0.201*** | 0.198*** | 0.0106 | -0.208*** | 0.0625* | 0.0561° | 0.0593° |
| | (1.79) | (-5.85) | (4.09) | (0.12) | (-6.06) | (2.21) | (1.94) | (1.85) |
| *N* | 918 | 765 | 639 | 567 | 761 | 816 | 816 | 812 |
| $R^2$ | 0.2115 | 0.1879 | 0.2692 | 0.2151 | 0.1942 | 0.2173 | 0.2044 | 0.1808 |

*Robust t* statistics in parentheses ° $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

## Table 3. Per capita NO2 emission (kg/p) – Fixed effect

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| | no2a | no2a | no2a | no2a | no2a | no2a | no2a | no2a |
| gdp | 0.000133$^{*}$ | 0.000666$^{***}$ | 0.000344$^{\circ}$ | 0.00136$^{***}$ | 0.000654$^{***}$ | 0.000178$^{*}$ | 0.000212$^{*}$ | 0.000210$^{**}$ |
| | (2.49) | (4.40) | (1.79) | (4.04) | (4.38) | (2.31) | (2.59) | (3.15) |
| gdp2 | -0.00101 | -0.0130$^{***}$ | -0.00214 | -0.0238$^{***}$ | -0.0130$^{***}$ | -0.00208 | -0.00258 | -0.00287$^{*}$ |
| | (-0.85) | (-3.84) | (-0.59) | (-3.54) | (-3.88) | (-1.30) | (-1.59) | (-2.18) |
| gdp3 | 0.00557 | 0.0630$^{***}$ | -0.0137 | 0.0967$^{**}$ | 0.0627$^{***}$ | 0.0115 | 0.0134$^{\circ}$ | 0.0136$^{\circ}$ |
| | (0.90) | (3.86) | (-0.41) | (2.88) | (3.88) | (1.40) | (1.66) | (1.99) |
| popd | 0.0000059 | -0.00000249 | 0.000388 | 0.000222 | -0.0000015 | 0.0000049 | 0.0000044 | 0.0000268$^{\circ}$ |
| | (0.56) | (-0.29) | (1.25) | (1.23) | (-0.18) | (0.46) | (0.44) | (1.68) |
| gini | | 0.527$^{***}$ | | 0.834$^{**}$ | 0.546$^{***}$ | | | |
| | | (3.65) | | (2.89) | (3.78) | | | |
| lc | | | 0.000457$^{**}$ | 0.000299$^{\circ}$ | | | | |
| | | | (3.32) | (1.96) | | | | |
| lc_2 | | | -0.0000115$^{**}$ | -0.0000085$^{\circ}$ | | | | |
| | | | (-3.45) | (-1.87) | | | | |
| lc_3 | | | 7.08e-08$^{**}$ | 4.72e-08$^{\circ}$ | | | | |
| | | | (3.48) | (1.67) | | | | |
| lg_c | | | | | 0.000319 | | | |
| | | | | | (1.15) | | | |
| lg_c_2 | | | | | -0.0000108 | | | |
| | | | | | (-1.37) | | | |
| lg_c_3 | | | | | 6.16e-08 | | | |
| | | | | | (1.18) | | | |
| lg_c_low | | | | | | -0.00900$^{*}$ | | |
| | | | | | | (-2.03) | | |
| lg_c_mean | | | | | | -0.00177 | | |
| | | | | | | (-0.77) | | |
| lg_c_high | | | | | | 0.00158 | | |
| | | | | | | (0.53) | | |
| lggdp_c_low | | | | | | | -0.403$^{*}$ | |
| | | | | | | | (-2.10) | |
| ggdp_c_mean | | | | | | | -0.0852 | |
| | | | | | | | (-1.06) | |
| ggdp_dc_high | | | | | | | 0.143 | |
| | | | | | | | (1.64) | |
| lg_c_gdp | | | | | | | | 0.0237$^{**}$ |
| | | | | | | | | (2.76) |
| lg_c_2_gdp | | | | | | | | -0.000415$^{*}$ |
| | | | | | | | | (-2.15) |
| lg_c_3_gdp | | | | | | | | 0.0000022$^{*}$ |
| | | | | | | | | (2.20) |
| _cons | -0.0201$^{*}$ | -0.298$^{***}$ | -0.107$^{*}$ | -0.580$^{**}$ | -0.304$^{***}$ | -0.0220$^{\circ}$ | -0.0294$^{*}$ | -0.0291$^{*}$ |
| | (-2.25) | (-3.86) | (-2.55) | (-3.39) | (-3.98) | (-1.79) | (-2.21) | (-2.41) |
| $N$ | 918 | 765 | 639 | 567 | 761 | 816 | 816 | 812 |
| $R^2$ | 0.2304 | 0.2234 | 0.2557 | 0.2267 | 0.2098 | 0.2156 | 0.2097 | 0.2319 |

*Robust t* statistics in parentheses $^{\circ}$ $p < 0.10$, $^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$

## Table 4. Per capita CO2 emission (kg/p) – Arellano Bond

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| | co2a | co2a | co2a | co2a | co2a | co2a | co2a | co2a |
| L.co2a | 0.236$^{*}$ | 0.114 | 0.135$^{\circ}$ | 0.0551 | 0.112 | 0.205 | 0.207 | 0.203 |
| | (1.97) | (0.79) | (1.82) | (0.52) | (0.78) | (1.59) | (1.59) | (1.54) |
| gdp | 0.0704$^{*}$ | 0.0432 | 0.0792 | 0.0583 | 0.0441 | 0.0656$^{*}$ | 0.0657$^{*}$ | 0.0662$^{*}$ |
| | (2.22) | (1.06) | (1.58) | (0.92) | (1.06) | (2.26) | (2.25) | (2.29) |
| gdp2 | -1.702$^{**}$ | -1.048 | -2.163$^{*}$ | -1.625 | -1.067 | -1.609$^{**}$ | -1.611$^{**}$ | -1.607$^{**}$ |
| | (-2.87) | (-1.50) | (-2.31) | (-1.39) | (-1.50) | (-3.08) | (-3.08) | (-3.14) |
| gdp3 | 7.984$^{**}$ | 4.996 | 11.97$^{**}$ | 8.702$^{\circ}$ | 5.108 | 7.583$^{**}$ | 7.595$^{**}$ | 7.492$^{**}$ |
| | (2.91) | (1.54) | (2.62) | (1.65) | (1.55) | (3.15) | (3.15) | (3.18) |
| popd | -0.00309$^{*}$ | -0.00153 | 0.00430$^{\circ}$ | 0.000937 | -0.00139 | -0.00241$^{\circ}$ | -0.00240$^{\circ}$ | -0.00230$^{\circ}$ |
| | (-2.27) | (-0.86) | (1.83) | (0.39) | (-0.81) | (-1.79) | (-1.80) | (-1.74) |
| gini | | -38.94$^{*}$ | | -32.85 | -40.06$^{*}$ | | | |
| | | (-2.28) | | (-1.55) | (-2.27) | | | |
| L.c | | | 0.00647 | 0.00811 | | | | |
| | | | (0.59) | (0.70) | | | | |
| L.c_2 | | | -0.000123 | -0.000155 | | | | |
| | | | (-0.44) | (-0.62) | | | | |
| L.c_3 | | | 0.000000805 | 0.00000105 | | | | |
| | | | (0.46) | (0.67) | | | | |
| L.g_c | | | | | 0.0179 | | | |
| | | | | | (0.52) | | | |
| L.g_c_2 | | | | | -0.000214 | | | |
| | | | | | (-0.27) | | | |
| L.g_c_3 | | | | | 0.00000138 | | | |
| | | | | | (0.28) | | | |
| L.g_c_low | | | | | | -0.0597 | | |
| | | | | | | (-0.23) | | |
| L.g_c_mean | | | | | | -0.253 | | |
| | | | | | | (-1.47) | | |
| L.g_c_high | | | | | | -0.115 | | |
| | | | | | | (-0.35) | | |
| L.ggdp_c_low | | | | | | | -4.841 | |
| | | | | | | | (-0.54) | |
| L.ggdp_c_mean | | | | | | | -9.403$^{\circ}$ | |
| | | | | | | | (-1.87) | |
| L.ggdp_c_high | | | | | | | -9.287 | |
| | | | | | | | (-1.05) | |
| L.g_c_gdp | | | | | | | | -0.0378 |
| | | | | | | | | (-0.04) |
| L.g_c_2_gdp | | | | | | | | -0.0160 |
| | | | | | | | | (-0.71) |
| L.g_c_3_gdp | | | | | | | | 0.000151 |
| | | | | | | | | (1.07) |
| _cons | 3.338 | 20.44 | 4.911 | 21.45 | 23.75 | 2.153 | 2.139 | 4.268 |
| | (0.48) | (1.51) | (0.47) | (1.04) | (1.54) | (0.37) | (0.36) | (0.59) |
| *N* | 816 | 663 | 511 | 450 | 658 | 714 | 714 | 709 |
| *Arellano-bond 1* | -2.589$^{**}$ | -2.5263$^{**}$ | -1.8073$^{\circ}$ | -1.8734$^{\circ}$ | -2.5238$^{**}$ | -2.4895$^{**}$ | -2.5075$^{**}$ | -2.4636$^{**}$ |
| *Arellano-bond 2* | 1.399 | 1.2167 | 1.1491 | 1.1184 | 1.2223 | 1.2663 | 1.2682 | 1.2459 |
| *Wald test* | 279.31$^{*}$ | 249.12$^{*}$ | 373.59$^{*}$ | 163.21$^{*}$ | 278.80$^{*}$ | 295.90$^{*}$ | 302.54$^{*}$ | 274.72$^{*}$ |

*Robust t* statistics in parentheses $^{\circ}$ $p < 0.10$, $^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$

## Table 5. Per capita SO2 emission (kg/p) – Arellano Bond

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| | so2a | so2a | so2a | so2a | so2a | so2a | so2a | so2a |
| L.so2a | 0.778*** | 0.674*** | 0.601*** | 0.535*** | 0.667*** | 0.714*** | 0.719*** | 0.730*** |
| | (18.90) | (11.74) | (10.94) | (8.74) | (11.51) | (14.92) | (14.88) | (15.09) |
| gdp | -0.000636 | -0.000670 | -0.00352* | -0.00414* | -0.000684 | -0.000901 | -0.00091 | -0.00079 |
| | (-0.89) | (-0.86) | (-2.02) | (-2.20) | (-0.87) | (-1.05) | (-1.04) | (-0.93) |
| gdp2 | 0.0130 | 0.0107 | 0.0662* | 0.0772* | 0.0104 | 0.0168 | 0.0169 | 0.0144 |
| | (0.96) | (0.73) | (2.03) | (2.18) | (0.71) | (1.03) | (1.02) | (0.90) |
| gdp3 | -0.0567 | -0.0430 | -0.322* | -0.364* | -0.0411 | -0.0728 | -0.0731 | -0.0609 |
| | (-0.93) | (-0.64) | (-2.05) | (-2.18) | (-0.61) | (-0.99) | (-0.98) | (-0.84) |
| popd | 0.0000155 | 0.0000064 | 0.000108° | 0.0000910** | 0.0000158 | 0.0000218 | 0.000021 | 0.000034 |
| | (0.64) | (0.43) | (1.75) | (2.63) | (1.01) | (0.97) | (0.91) | (1.37) |
| gini | | 0.666* | | 0.191 | 0.640* | | | |
| | | (2.33) | | (1.05) | (2.33) | | | |
| L.c | | | 0.000836* | 0.000933* | | | | |
| | | | (2.28) | (2.27) | | | | |
| L.c_2 | | | -0.0000177* | -0.0000202* | | | | |
| | | | (-2.26) | (-2.34) | | | | |
| L.c_3 | | | 0.00000011* | 0.00000012* | | | | |
| | | | (2.24) | (2.34) | | | | |
| L.g_c | | | | | 0.00163° | | | |
| | | | | | (1.73) | | | |
| L.g_c_2 | | | | | -0.0000368° | | | |
| | | | | | (-1.84) | | | |
| L.g_c_3 | | | | | 0.00000022° | | | |
| | | | | | (1.87) | | | |
| L.g_c_low | | | | | | -0.0138* | | |
| | | | | | | (-2.08) | | |
| L.g_c_mean | | | | | | 0.0111 | | |
| | | | | | | (1.12) | | |
| L.g_c_high | | | | | | 0.00785 | | |
| | | | | | | (1.12) | | |
| L.ggdp_c_low | | | | | | | -0.495* | |
| | | | | | | | (-2.54) | |
| L.ggdp_c_mean | | | | | | | 0.230 | |
| | | | | | | | (1.02) | |
| L.ggdp_c_high | | | | | | | 0.215 | |
| | | | | | | | (1.21) | |
| L.g_c_gdp | | | | | | | | 0.0375° |
| | | | | | | | | (1.74) |
| L.g_c_2_gdp | | | | | | | | -0.00063° |
| | | | | | | | | (-1.67) |
| L.g_c_3_gdp | | | | | | | | 0.0000035° |
| | | | | | | | | (1.59) |
| _cons | 0.0842 | -0.135 | 0.539* | 0.562° | -0.142 | 0.142 | 0.144 | 0.122 |
| | (0.82) | (-1.09) | (2.00) | (1.94) | (-1.06) | (1.15) | (1.15) | (0.98) |
| *N* | 816 | 663 | 511 | 450 | 658 | 714 | 714 | 709 |
| *Arellano-bond 1* | -1.7038° | -1.6714° | -1.4688 | -1.4371 | -1.6764° | -1.7243° | -1.6914° | -1.6768° |
| *Arellano-bond 2* | 0.65938 | 0.65747 | 0.81717 | 0.79622 | 0.67267 | 0.70697 | 0.68168 | 0.70076 |
| *Wald test* | 8587.68* | 2227.86* | 2537.15* | 1222.85* | 2360.58* | 12362.25* | 7774.64* | 5365.62* |

*Robust t* statistics in parentheses ° $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

**Table 6. Per capita NO2 emission (kg/p) – Arellano Bond**

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| | no2a | no2a | no2a | no2a | no2a | no2a | no2a | no2a |
| L.no2a | 0.650*** | 0.543*** | 0.317*** | 0.162* | 0.543*** | 0.609*** | 0.606*** | 0.596*** |
| | (38.91) | (24.02) | (4.28) | (2.21) | (23.64) | (28.90) | (28.57) | (25.10) |
| gdp | -0.000535 | -0.000336 | -0.00117** | -0.00174** | -0.000329 | -0.000543 | -0.00053 | -0.00056 |
| | (-1.41) | (-1.06) | (-2.98) | (-2.98) | (-1.05) | (-1.21) | (-1.19) | (-1.21) |
| gdp2 | 0.0132° | 0.00995 | 0.0264*** | 0.0408** | 0.00966 | 0.0148 | 0.0146 | 0.0144 |
| | (1.65) | (1.32) | (3.35) | (2.69) | (1.30) | (1.45) | (1.44) | (1.44) |
| gdp3 | -0.0588 | -0.0454 | -0.138*** | -0.209* | -0.0439 | -0.0677 | -0.0668 | -0.0650 |
| | (-1.61) | (-1.26) | (-3.68) | (-2.55) | (-1.23) | (-1.44) | (-1.43) | (-1.40) |
| popd | 0.000022 | 0.0000073 | -0.00000085 | -0.000086 | 0.000012 | 0.000021 | 0.000021 | 0.000034* |
| | (1.57) | (0.37) | (-0.02) | (-1.23) | (0.62) | (1.50) | (1.50) | (2.00) |
| gini | | 0.422° | | -0.322 | 0.414° | | | |
| | | (1.90) | | (-0.78) | (1.90) | | | |
| L.c | | | 0.000169 | 0.000204 | | | | |
| | | | (1.56) | (1.61) | | | | |
| L.c_2 | | | -0.0000055* | -0.000006° | | | | |
| | | | (-2.02) | (-1.89) | | | | |
| L.c_3 | | | 3.28e-08° | 3.98e-08° | | | | |
| | | | (1.92) | (1.89) | | | | |
| L.g_c | | | | | 0.000778* | | | |
| | | | | | (2.18) | | | |
| L.g_c_2 | | | | | -0.0000189* | | | |
| | | | | | (-2.37) | | | |
| L.g_c_3 | | | | | 0.00000011* | | | |
| | | | | | (2.48) | | | |
| L.g_c_low | | | | | | -0.00781* | | |
| | | | | | | (-2.48) | | |
| L.g_dc_mean | | | | | | -0.00267 | | |
| | | | | | | (-0.99) | | |
| L.g_c_high | | | | | | -0.00646 | | |
| | | | | | | (-1.63) | | |
| L.ggdp_c_low | | | | | | | -0.225* | |
| | | | | | | | (-1.98) | |
| L.ggdp_c_mean | | | | | | | -0.0631 | |
| | | | | | | | (-0.82) | |
| L.ggdp_c_high | | | | | | | -0.0818 | |
| | | | | | | | (-0.91) | |
| L.g_c_gdp | | | | | | | | 0.0290° |
| | | | | | | | | (1.74) |
| L.g_c_2_gdp | | | | | | | | -0.000463° |
| | | | | | | | | (-1.76) |
| L.g_c_3_gdp | | | | | | | | 0.000002° |
| | | | | | | | | (1.72) |
| _cons | 0.0427 | -0.125 | 0.147* | 0.354 | -0.161° | 0.0603 | 0.0570 | 0.0285 |
| | (0.87) | (-1.45) | (2.57) | (1.59) | (-1.66) | (1.06) | (1.02) | (0.52) |
| *N* | 816 | 663 | 511 | 450 | 658 | 714 | 714 | 709 |
| *Arellano-bond 1* | -1.3394 | -1.3332 | -1.6558° | -1.8734° | -1.334 | -1.3279 | -1.3274 | -1.3476 |
| *Arellano-bond 2* | -0.80013 | -0.90847 | -0.90919 | -0.94564 | -0.90583 | -0.90873 | -0.89816 | -0.78953 |
| *Wald test* | 10990.01* | 4886.76* | 2087.38* | 1016.13* | 8349.50* | 16557.76* | 14645.03* | 7093.42* |

*Robust t* statistics in parentheses ° $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

## Table 7. Descriptive Statistics

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| **so2a** | 918 | 0.0543127 | 0.0687653 | 0.0000159 | 0.5539507 |
| **co2a** | 918 | 11.51106 | 14.20056 | 0.0144516 | 95.69136 |
| **no2a** | 918 | 0.0321797 | 0.0444372 | 0.0001592 | 0.4218313 |
| **gdp** | 1326 | 310.0561 | 125.3725 | 146.5216 | 1267.849 |
| **gdp2** | 1326 | 11.18412 | 14.51296 | 2.146858 | 160.744 |
| **gdp3** | 1326 | 0.5195426 | 1.608161 | 0.0314561 | 20.37991 |
| **popd** | 1377 | 121.1835 | 460.9313 | 0.2843181 | 3626.528 |
| **gini** | 1122 | 0.4039153 | 0.031448 | 0.344 | 0.594 |
| **c** | 799 | 13.20401 | 17.17862 | 0 | 108 |
| **c_2** | 1165 | 345.4275 | 1100.873 | 0 | 11664 |
| **c_3** | 1165 | 18782.16 | 95470.21 | 0 | 1259712 |
| **g_c** | 963 | 4.441.873 | 6.950858 | 0 | 51.816 |
| **g_c_2** | 963 | 152.6649 | 515.3577 | 0 | 5540.4 |
| **g_c_3** | 963 | 8701.054 | 45062.12 | 0 | 598363.2 |
| **g_c_low** | 1122 | 0.068541 | 0.1493235 | 0 | 0.454 |
| **g_c_mean** | 1122 | 0.0574287 | 0.1416564 | 0 | 0.468 |
| **g_c_high** | 1122 | 0.2119314 | 0.2052125 | 0 | 0.594 |
| **g_c_gdp** | 963 | 0.1549278 | 0.3059222 | 0 | 3.205285 |
| **g_c_2_gdp** | 963 | 5.588454 | 19.94464 | 0 | 216.1997 |
| **g_c_3_gdp** | 963 | 319.3214 | 1687.502 | 0 | 23028.86 |
| **ggdp_c_low** | 1122 | 0.0018594 | 0.0041576 | 0 | 0.0212546 |
| **ggdp_c_mean** | 1122 | 0.0015839 | 0.0040184 | 0 | 0.0212702 |
| **ggdp_c_high** | 1122 | 0.0068847 | 0.0089064 | 0 | 0.0675931 |

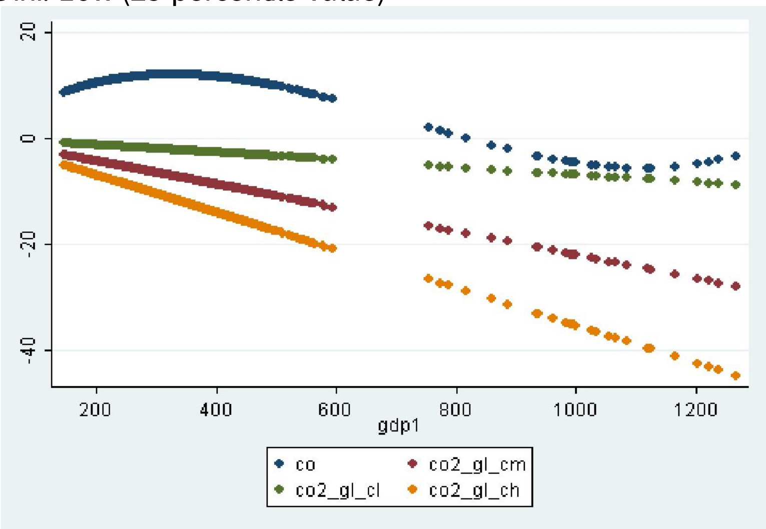
## Table 8. Correlation Matrix

| | gdp | gdp2 | gdp3 | popd | gini | c | c_2 | c_3 | g_c | g_c_2 | g_c_3 | g_c_l | g_c_m | g_c_h | ggdp_c_l | ggdp_c_m | ggdp_c_h | g_c_gdp | g_c_2_gdp | g_c_3_gdp |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **gdp** | 1.000 | | | | | | | | | | | | | | | | | | | |
| **gdp2** | 0.9395 | 1.000 | | | | | | | | | | | | | | | | | | |
| **gdp3** | 0.8360 | 0.9728 | 1.000 | | | | | | | | | | | | | | | | | |
| **popd** | 0.7564 | 0.9127 | 0.9596 | 1.000 | | | | | | | | | | | | | | | | |
| **gini** | 0.4064 | 0.4364 | 0.4272 | 0.4155 | 1.000 | | | | | | | | | | | | | | | |
| **c** | 0.2633 | 0.1918 | 0.1325 | 0.1728 | 0.4799 | 1.000 | | | | | | | | | | | | | | |
| **c_2** | 0.2004 | 0.1333 | 0.0792 | 0.0922 | 0.3845 | 0.9154 | 1.000 | | | | | | | | | | | | | |
| **c_3** | 0.1565 | 0.0957 | 0.0475 | 0.0506 | 0.3164 | 0.8088 | 0.9718 | 1.000 | | | | | | | | | | | | |
| **g_c** | 0.2938 | 0.2282 | 0.1698 | 0.2022 | 0.5232 | 0.9956 | 0.9248 | 0.8246 | 1.000 | | | | | | | | | | | |
| **g_c_2** | 0.2139 | 0.1490 | 0.0949 | 0.1038 | 0.4034 | 0.9047 | 0.9971 | 0.9754 | 0.9204 | 1.000 | | | | | | | | | | |
| **g_c_3** | 0.1630 | 0.1029 | 0.0544 | 0.0551 | 0.3275 | 0.7974 | 0.9642 | 0.9975 | 0.8180 | 0.9730 | 1.000 | | | | | | | | | |
| **g_c_l** | -0.1374 | -0.1046 | -0.0768 | -0.1286 | -0.2848 | -0.4249 | -0.2113 | -0.1400 | -0.4048 | -0.2041 | -0.1363 | 1.000 | | | | | | | | |
| **g_c_m** | -0.0913 | -0.0719 | -0.0564 | -0.0581 | -0.0110 | -0.1655 | -0.1611 | -0.1196 | -0.1669 | -0.1572 | -0.1166 | -0.3316 | 1.000 | | | | | | | |
| **g_c_h** | 0.2975 | 0.2496 | 0.2036 | 0.2473 | 0.4582 | 0.7827 | 0.5674 | 0.4180 | 0.7746 | 0.5573 | 0.4107 | -0.3456 | -0.3007 | 1.000 | | | | | | |
| **ggdp_c_l** | -0.0477 | -0.0512 | -0.0505 | -0.1237 | -0.2804 | -0.4125 | -0.2051 | -0.1359 | -0.3930 | -0.1981 | -0.1323 | 0.9702 | -0.3219 | -0.3356 | 1.000 | | | | | |
| **ggdp_c_m** | -0.0011 | -0.0161 | -0.0278 | -0.0481 | -0.0207 | -0.1610 | -0.1562 | -0.1160 | -0.1626 | -0.1525 | -0.1131 | -0.3215 | 0.9677 | -0.2915 | -0.3121 | 1.000 | | | | |
| **ggdp_c_h** | 0.5595 | 0.5750 | 0.5512 | 0.5708 | 0.5677 | 0.7062 | 0.5224 | 0.3906 | 0.7208 | 0.5244 | 0.3900 | -0.3011 | -0.2620 | 0.8982 | -0.2924 | -0.2540 | 1.000 | | | |
| **g_c_gdp** | 0.5305 | 0.5116 | 0.4654 | 0.4800 | 0.6067 | 0.9076 | 0.8551 | 0.7688 | 0.9331 | 0.8640 | 0.7712 | -0.3423 | -0.1673 | 0.7216 | -0.3316 | -0.1553 | 0.8173 | 1.000 | | |
| **g_c_2_gdp** | 0.3185 | 0.2760 | 0.2279 | 0.2301 | 0.4574 | 0.8692 | 0.9667 | 0.9532 | 0.8981 | 0.9799 | 0.9590 | -0.1906 | -0.1507 | 0.5408 | -0.1850 | -0.1454 | 0.5793 | 0.9095 | 1.000 | |
| **g_c_3_gdp** | 0.2066 | 0.1554 | 0.1089 | 0.1060 | 0.3550 | 0.7735 | 0.9426 | 0.9822 | 0.8027 | 0.9594 | 0.9920 | -0.1304 | -0.1120 | 0.4007 | -0.1266 | -0.1085 | 0.4117 | 0.7896 | 0.9687 | 1.000 |

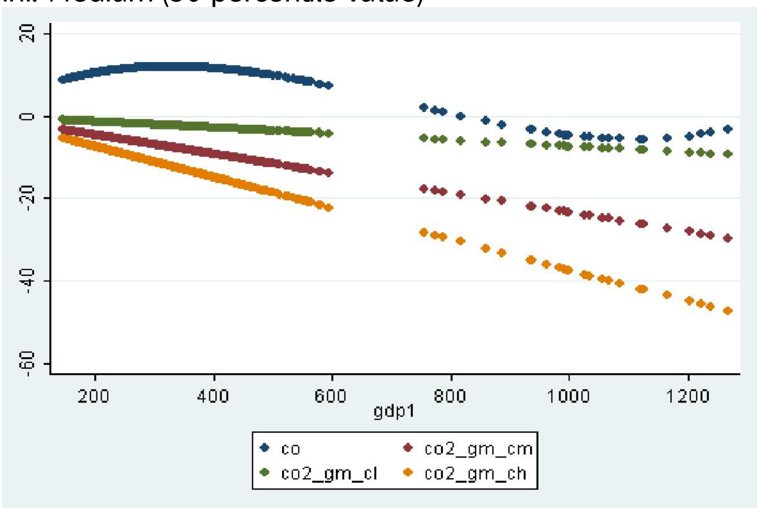
## 2. FIGURES

Figure 1. Per capita CO2 emission (kg/p): Up and downward movements in EKC – Fixed effect

Gini: Low (25 percentile value)




Gini: Medium (50 percentile value)




Gini: High (75 percentile value)

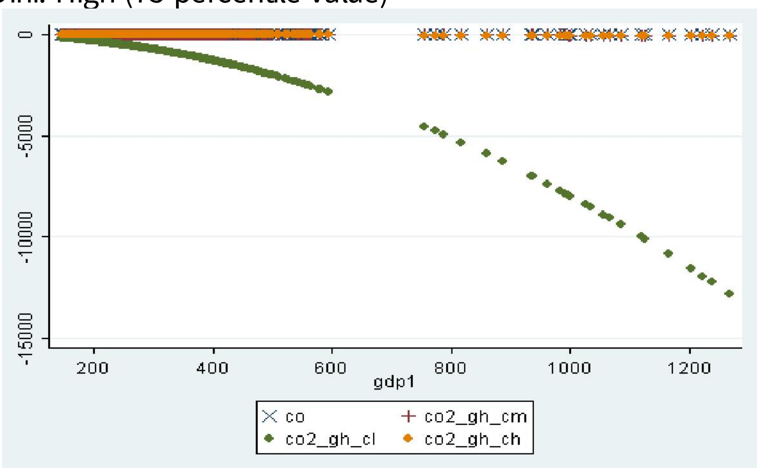
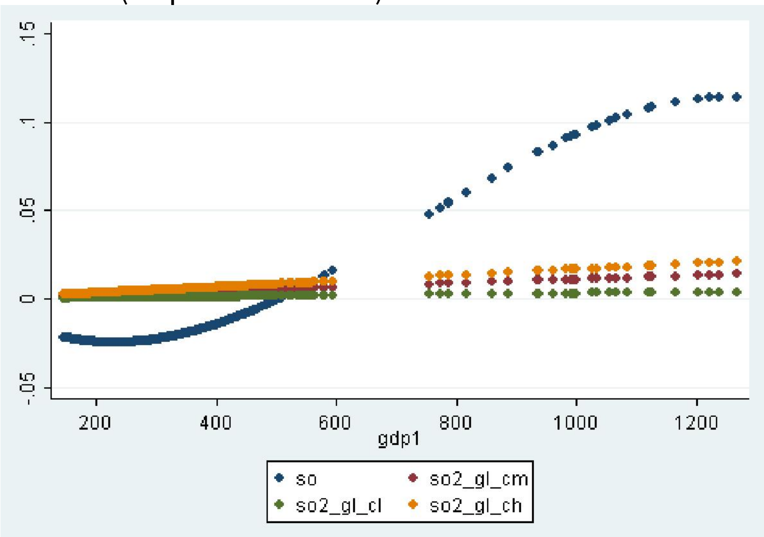
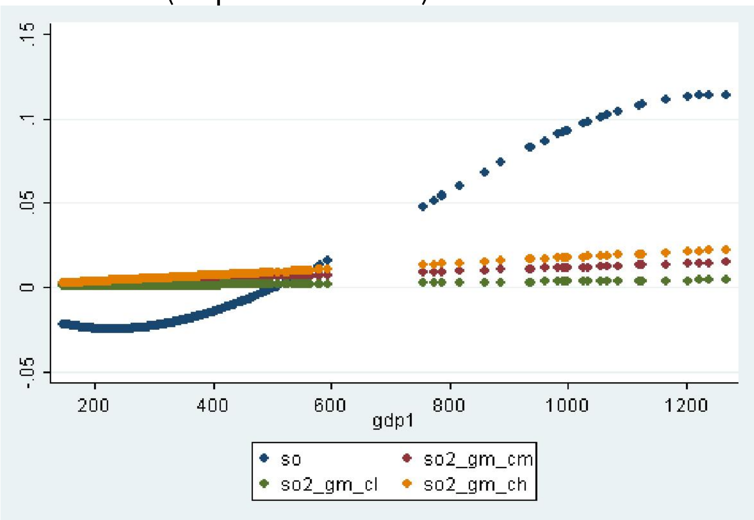


Figure 2. Per capita SO2 emission (kg/p): Up and downward movements in EKC – Fixed effect

Gini: Low (25 percentile value)




Gini: Medium (50 percentile value)




Gini: High (75 percentile value)

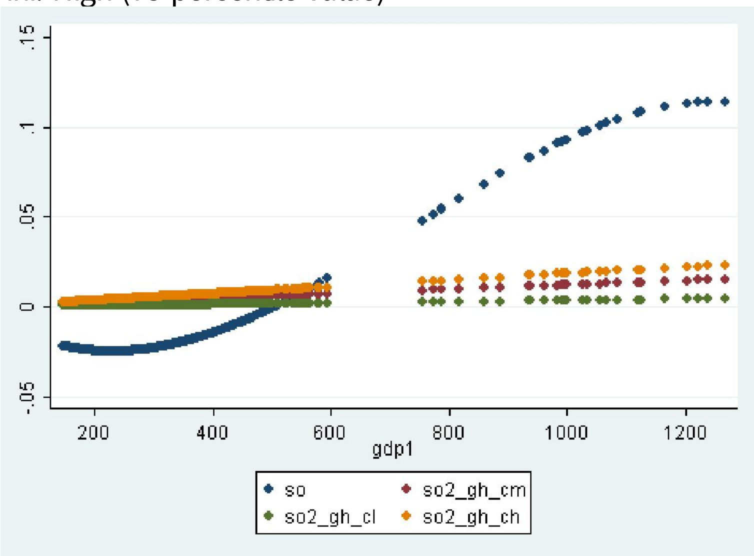
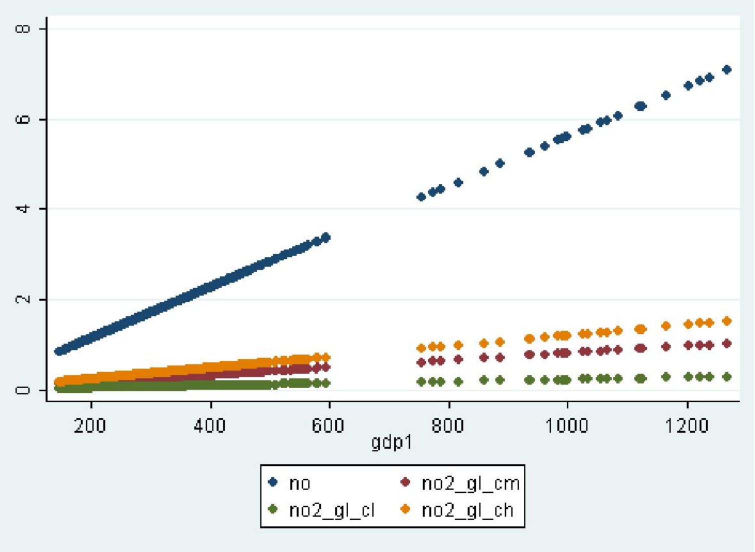
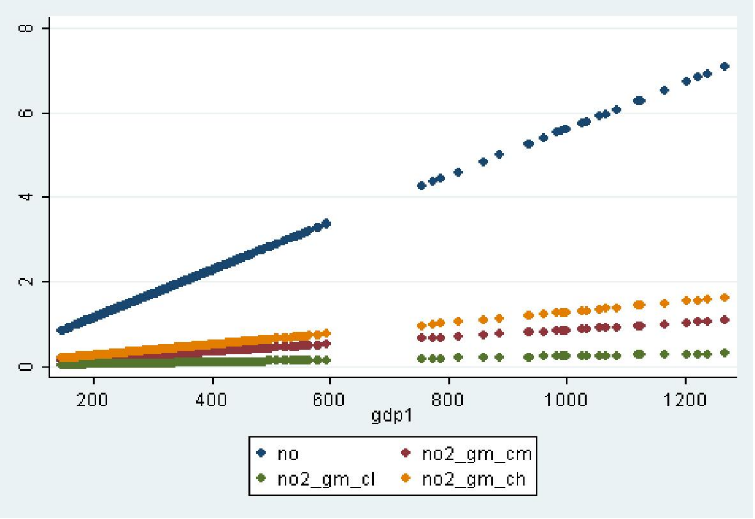


Figure 3. Per capita NO2 emission (kg/p): Up and downward movements in EKC – Fixed effect

Gini: Low (25 percentile value)




Gini: Medium (50 percentile value)




Gini: High (75 percentile value)

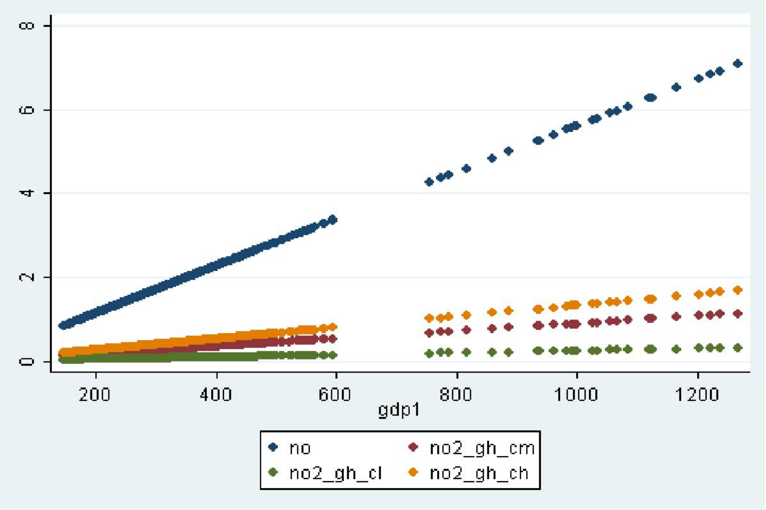
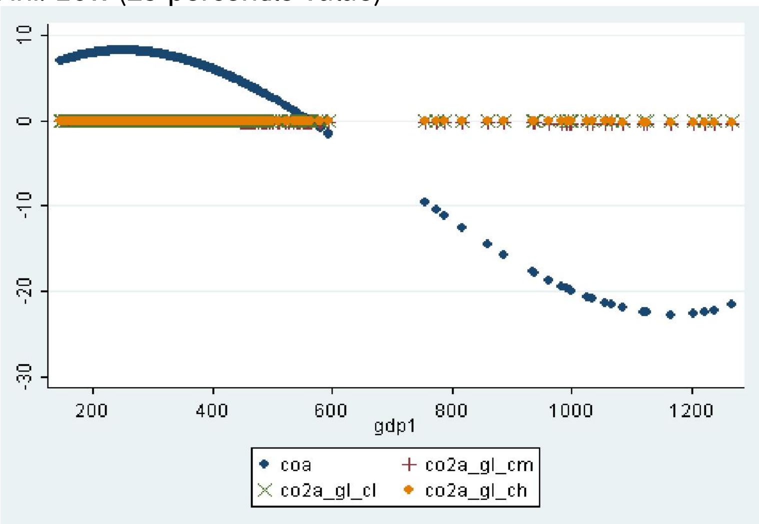
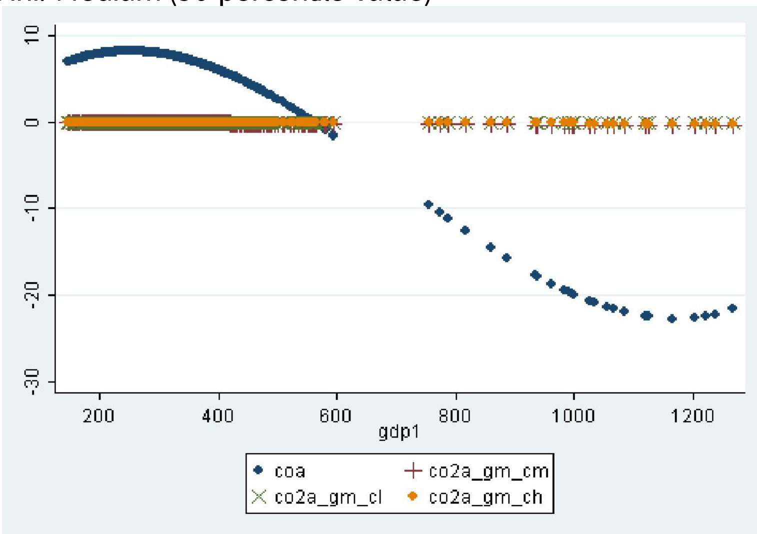


Figure 4. Per capita CO2 emission (kg/p): Up and downward movements in EKC – Arellano Bond

Gini: Low (25 percentile value)




Gini: Medium (50 percentile value)




Gini: High (75 percentile value)

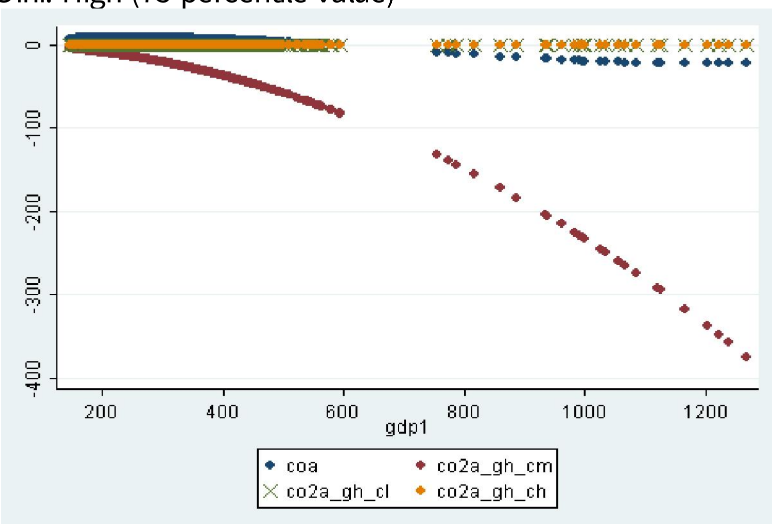
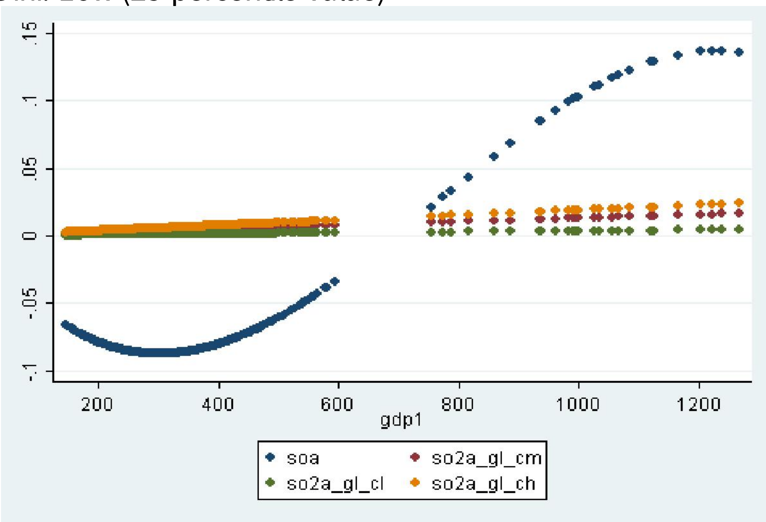
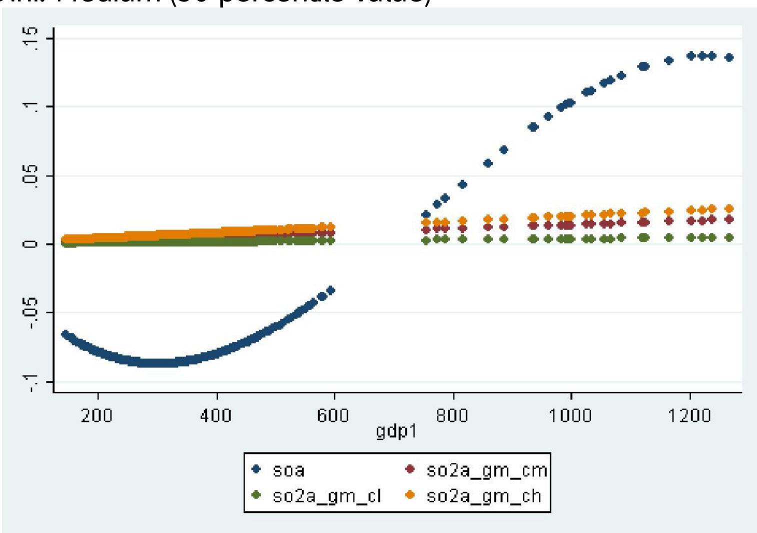


Figure 5. Per capita SO2 emission (kg/p): Up and downward movements in EKC – Arellano Bond

Gini: Low (25 percentile value)




Gini: Medium (50 percentile value)




Gini: High (75 percentile value)

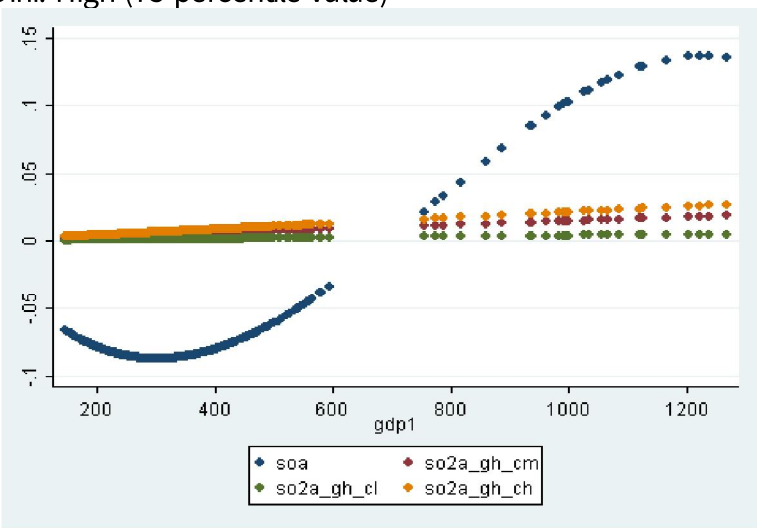
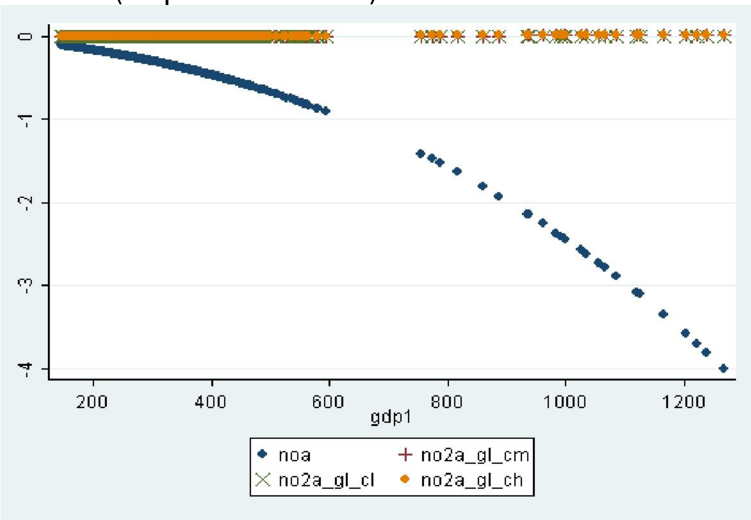
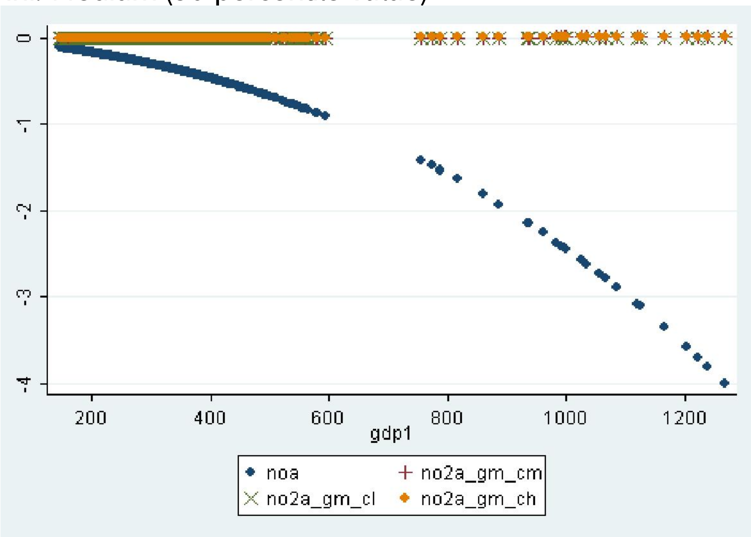


Figure 6. Per capita NO2 emission (kg/p): Up and downward movements in EKC – Arellano Bond

Gini: Low (25 percentile value)




Gini: Medium (50 percentile value)




Gini: High (75 percentile value)

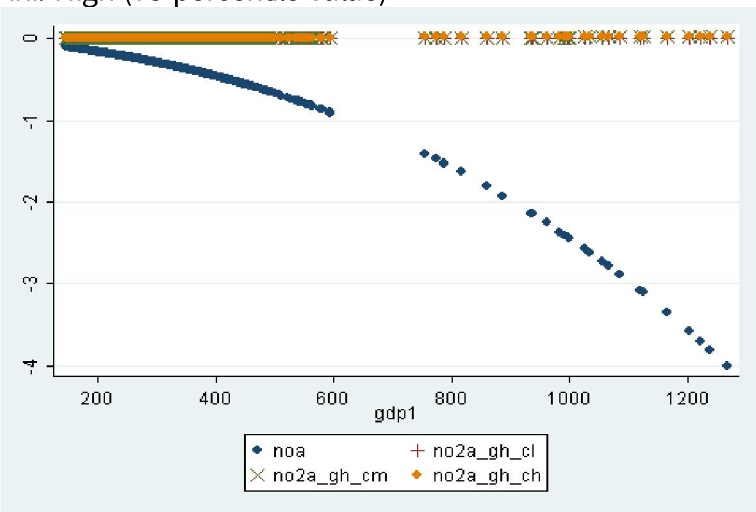
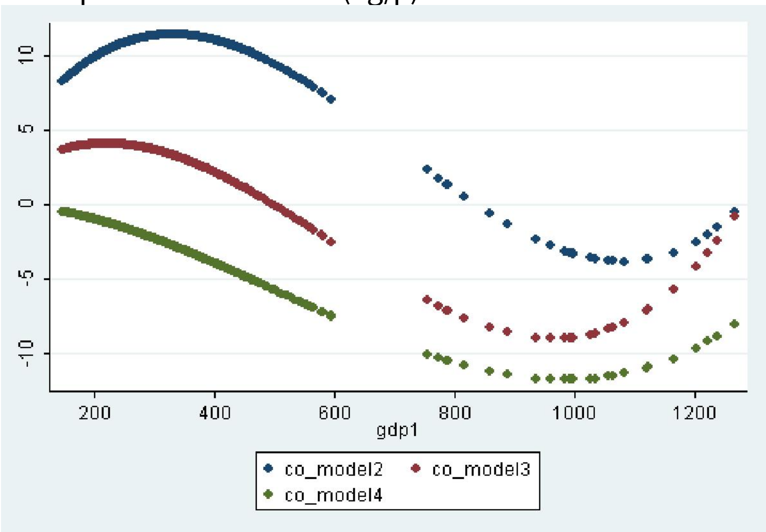
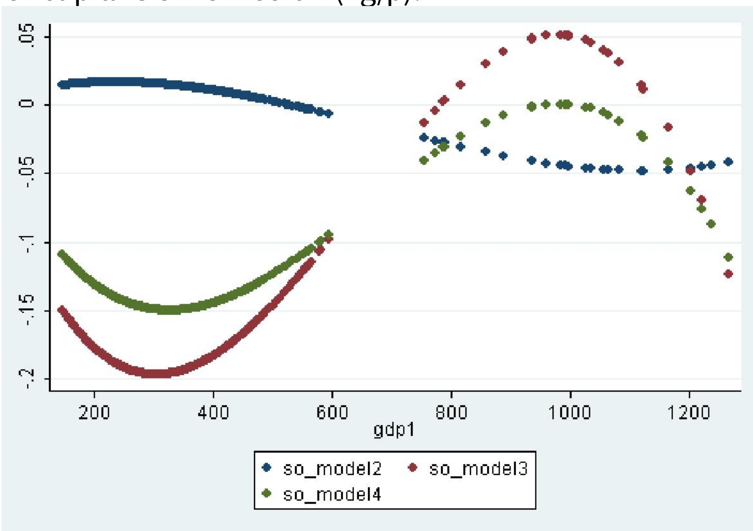


Figure 7. Up and downward movements in EKC for GDP – Fixed effect

Per capita CO2 emission (kg/p):




Per capita SO2 emission (kg/p):




Per capita NO2 emission (kg/p):

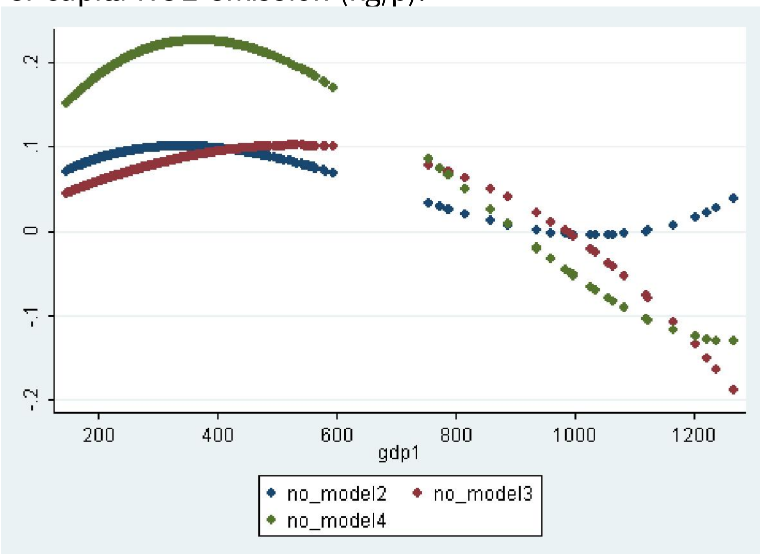
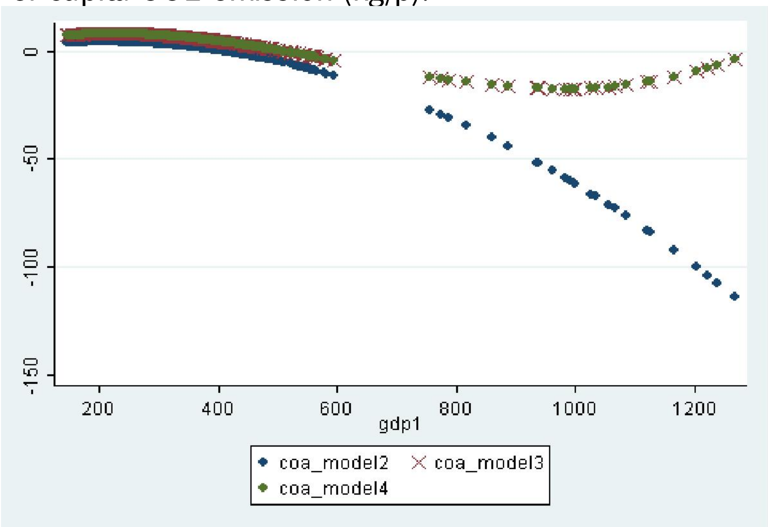
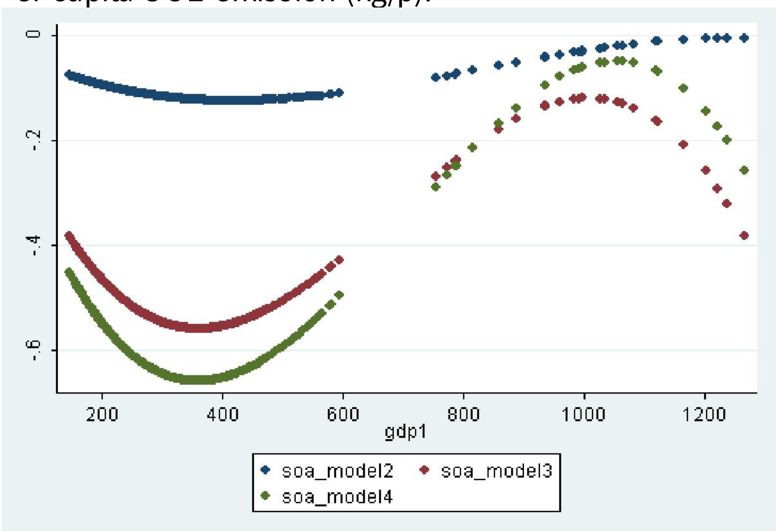


Figure 8. Up and downward movements in EKC Models for GDP (2)-(4) – Arellano Bond

Per capita CO2 emission (kg/p):




Per capita SO2 emission (kg/p):




Per capita NO2 emission (kg/p):

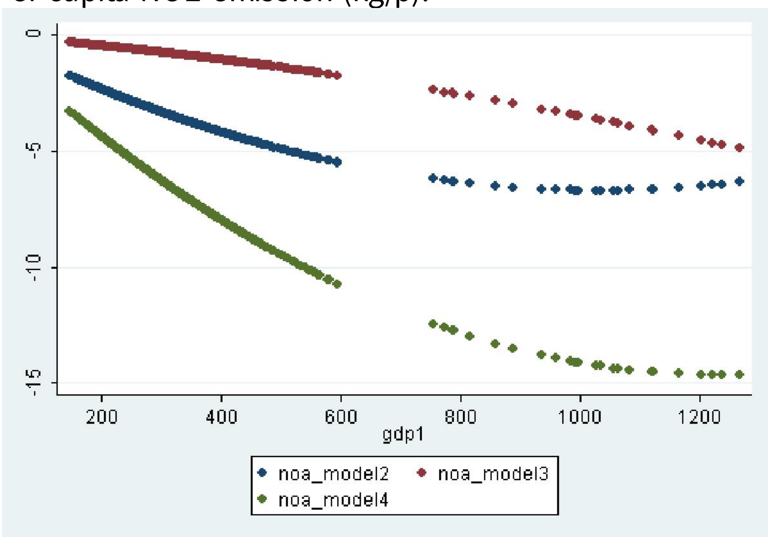
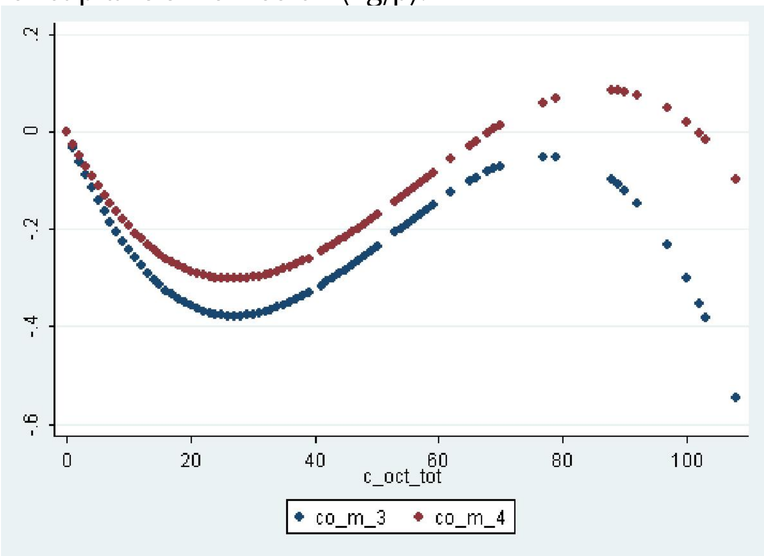
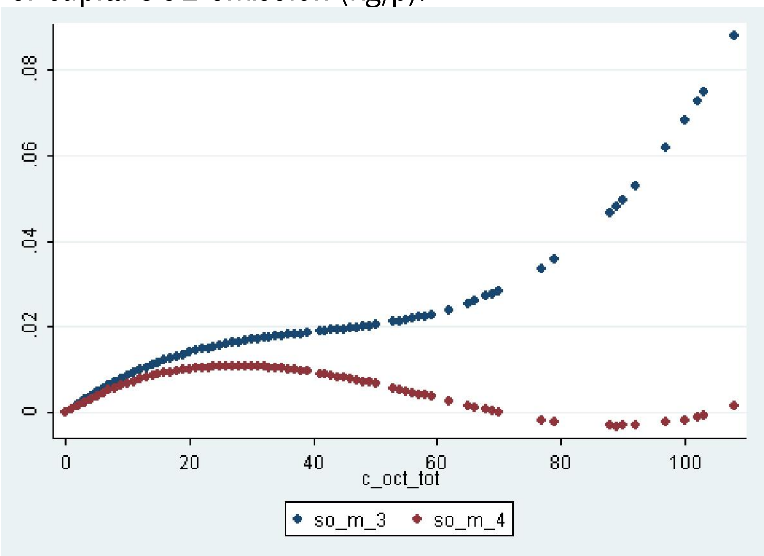


Figure 9. Up and downward movements in EKC for Corruption – Fixed effect

Per capita CO2 emission (kg/p):




Per capita SO2 emission (kg/p):




Per capita NO2 emission (kg/p):

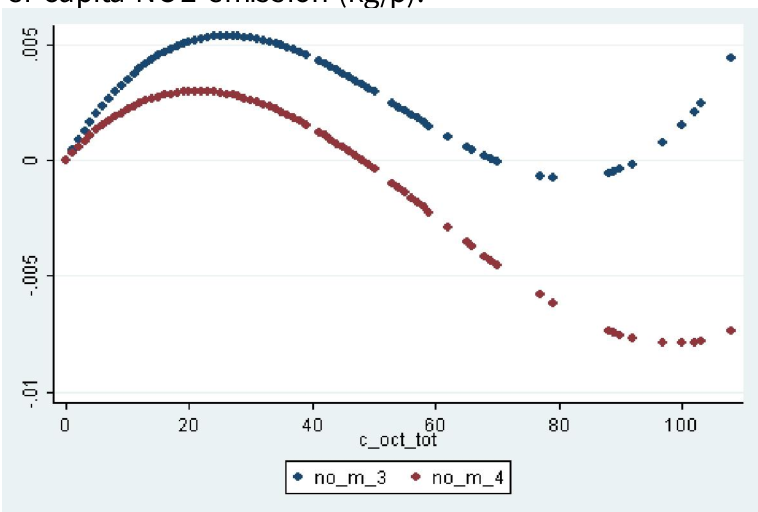
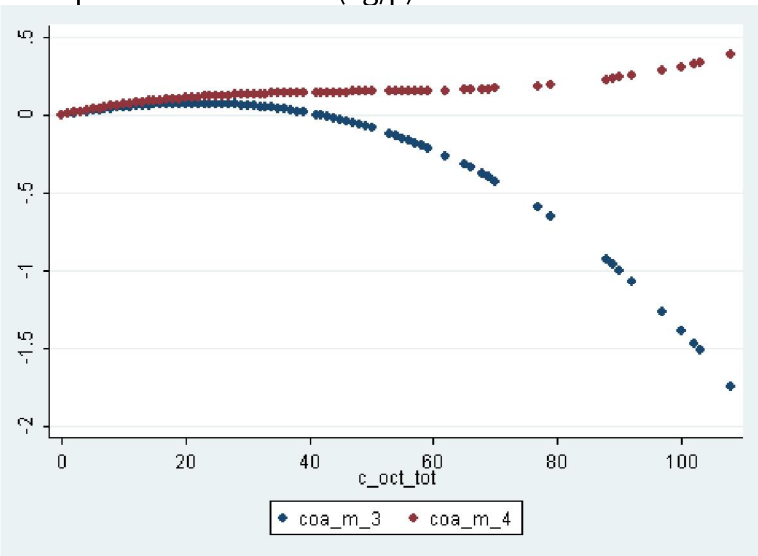
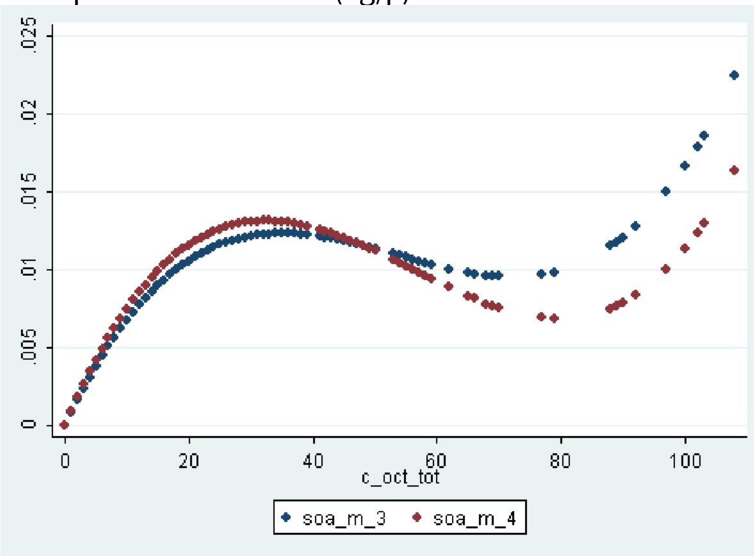


Figure 10. Up and downward movements in EKC Models for Corruption (2)-(4) - Arellano Bond

Per capita CO2 emission (kg/p):




Per capita SO2 emission (kg/p):




Per capita NO2 emission (kg/p):