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**A parametric and nonparametric analysis***


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**Abstract**

This paper examines convergence of per capita carbon dioxide ($CO_2$) emission for a panel of 124 countries taking into account the impact of the quality of government institutions. The analysis builds on both parametric and nonparametric panel data techniques, and we examine the $\beta$-convergence hypothesis in a neoclassical growth model setting with institutional quality as one of the independent variables. The results reveal evidence in support of $\beta$-convergence of per capita $CO_2$ emissions for the global sample, and for the sub-samples comprising OECD and non-OECD countries, respectively. The results indicate heterogeneity in $\beta$-convergence, which tends to vary with the level of the initial per capita $CO_2$ emissions. We also find evidence of a negative direct effect of institutional quality on growth in per capita $CO_2$ emissions. However, institutional quality also promotes economic growth, thus generating a positive indirect effect on emissions growth. Overall our empirical results suggest a positive total effect of institutions on growth in per capita $CO_2$ emission based on the global sample. Finally, we find some evidence of bias in the parametric approach, in particular in the case of the estimates for the convergence parameter at either end of the distribution.

**Keywords**: Carbon dioxide, Convergence, Institutions, Nonparametric approach

**JEL Classification: O43; Q54; Q56.**

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## 1. Introduction

The relationship between economic growth and environmental quality has been addressed both theoretically and empirically in numerous research studies. An important contribution of this literature has been to analyze the conditions under which an economy can achieve growing per capita incomes combined with non-deteriorating environmental quality (see Brock and Taylor 2005 for a review). One general condition, which emanates from the optimality conditions in a dynamic neoclassical growth model, is pollution ($\beta$) convergence, implying that in the long-run pollution should be bounded as well as approach a steady-state level even in the presence of positive growth in per capita GDP.

There is a rich empirical literature on pollution convergence, thus testing whether there is a negative growth-level relationship in environmental pollution. Most attention has been devoted to convergence of carbon dioxide ($CO_2$) emissions at the global or regional level (e.g., Aldy, 2006; Ezcerra, 2007; Strazicich and List, 2003; Nguyen Van, 2005; Panopoulou and Pantelidis, 2007; Westerlund and Basher, 2008; Camarero et al., 2008; Brock and Taylor, 2010; and Camarero et al., 2013). However, these studies typically devote very limited attention to the structural characteristics of countries (see the literature review in Pettersson et al., 2014). Specifically, the distribution of $CO_2$ emissions is often strongly related to the structure of a country's economy, and this hinges on that country's natural endowments (e.g., fossil fuel reserves), development level, and its comparative advantage in the production of various goods. All these conditions, in turn, are not preset requirements, but depend on the decisions of households, firms and governments, as well as the institutional frameworks within which these decisions take place. In this paper we address the economic and institutional determinants of $CO_2$ emission pathways across countries at the global level.

There is a strong consensus in the economics literature that the quality of institutions (e.g., the effectiveness of government and public administration, rule of law, control of corruption etc.) has had a decisive impact on long-term economic development (North, 1990). Institutions are very important for the efficient implementation of any policy, be it banking, labor or environmental policies. They are likely to be particularly important in areas where the behavior of individuals or firms is difficult to monitor and control. In the area of environmental pollution, it is widely recognized that relatively stringent regulations are needed to reduce hazardous emissions. Still, regardless of whether this is done via direct controls, economic instruments or softer policy instruments (e.g., voluntary industry agreements, environmental certification schemes, information measures etc.), legitimate institutions are necessary for these regulatory measures to be effective. This is likely of particular concern in developing countries, which often struggle in achieving reductions in both poverty levels and environmental pollution (e.g., Dasgupta et al., 2004). In the developing world the presence of poor institutions often hamper investments in productive activities (e.g., Kirkpatrick and Parker, 2004).

Over time researchers have devoted increased attention to the relationship between institutional quality and environmental pollution (e.g., Congleton, 1992), but the empirical literature is limited. One stream of the literature investigates the impact of democracy on different environmental indicators, including $CO_2$ emissions (e.g., Farzin and Bond, 2006; Winslow, 2005; Bernauer and Koubi, 2009; Fredriksson and Neumayer, 2013). Bernauer and Koubi (2009) also investigate the role of presidential versus parliamentary systems (in the empirical context of sulfur dioxide emissions). Few studies, though, address the impact of institutional quality. Two recent exceptions include Gani (2012) and Lau et al. (2014), which both investigate the relationship between $CO_2$ emissions and the quality of government institutions. However, none of these studies build on the necessary theoretical underpinnings, e.g., specifying the convergence conditions.

The main objective of this paper is to analyze the relationship between per capita $CO_2$ emissions, GDP per capita, and institutional quality across a global panel of 124 countries over the time period 1985-2010. The contribution of the paper lies in: (a) its emphasis on the role of government institutions and GDP for the convergence of per capita $CO_2$ emissions; (b) the use of an empirical specification that can be derived from a dynamic model of economic growth and optimal emission reduction (Ordás Criado et al., 2011); and (c) a comparison of parametric versus non-parametric methods.

First, the empirical analysis relies on four different dimensions of institutional quality as covered in the World Bank’s Worldwide Governance Indicators (Kaufman et al. 2009). Specifically, we address a combined measure (using principal component analysis) of the following dimensions: (a) government effectiveness (e.g., quality and competence of public service provision, independence from political pressures etc.); (b) regulatory quality (e.g., lack of excessive and arbitrary regulations); (c) rule of law (e.g., fair and predictable rules, effectiveness of the judiciary); and (d) lack of exercise of public power for private gains). Overall, in countries with high institutional quality, governments can enforce regulations relating to $CO_2$ emissions with greater efficiency, and private enterprises will not feel hesitant to comply. This suggests that it is reasonable to expect a negative *direct* relationship between higher institutional qualities on the one hand and per capita $CO_2$ emissions on the other. Good institutions also secure property rights and this creates incentives for an efficient use of resources.

Second, since institutions also matter greatly for economic growth, we could in turn expect an indirect effect due to the impact of higher growth rates on emission levels. In other words, while economic growth (ceteris paribus) typically leads to higher emissions, efficient institutions can moderate this effect. While this paper examines $CO_2$ emission dynamics in the context of conditional $\beta$-convergence (i.e., controlling for the role of institutional quality), it also addresses the positive interaction between $CO_2$ emission growth and per capita income growth. Our reduced-form (convergence) regression model builds on the work presented in Ordás Criado et al. (2011), who develop a neoclassical growth model with endogenous emission reduction.

Finally, we also employ nonparametric methods. This approach relaxes the functional specification for the empirical model, and also accommodates all forms of interaction between the regressors. The motivation for this is that a priori specifying the functional relations between the dependent and independent variables could result in specification bias and inconsistent estimates. Therefore, using an approach that is robust to specification bias will at least extend our knowledge on two counts. Firstly, it indicates if the popular linear specification is the appropriate specification for $CO_2$ emission convergence models. Secondly, our approach also assesses the direction and the magnitude of any detected bias associated with the linear specification.

The rest of the paper is organized as follows: section 2 provides the theoretical background and the econometric methodology for the study, we present the description of the data, the data sources and summary statistics in section 3, section 4 contains the empirical results and a discussion of the results, while the conclusions are presented in section 5.

## 2. Theoretical and Methodological Issues

### 2.1 Theoretical background

The standard theoretical literature on the relationship between economic growth and pollution dynamics started with the work by Keeler et al. (1971), in which the focus was on the interaction between capital accumulation and emission intensities. Most of the theoretical models focusing on the relationship between economic growth and pollution use the emission function to establish the link between these two variables. The emission function assumes that productive processes generate pollution, and pollution is assumed to depend on output (i.e., the production process). A popular variant of the general emission function is a function that incorporates pollution abatement in addition to output as the key drivers of pollution. In these emission functions, the input mix does not enter directly as a driver of emissions but it does so indirectly via output.

Previous theoretical studies that have used the emission function to derive the relationship between economic activity and pollution include Van der Ploeg and Withagen (1991), Bovenberg and Smulders (1995), and Stockey (1998). However, the focus of these cited studies have not been on deriving theoretical models that could be used in testing the pollution convergence hypothesis. The only studies that have focused on establishing a theoretical model that can be applied to data for testing this hypothesis are those developed by Brock and Taylor (2005, 2010) and Ordás Criado et al. (2011). The model developed by Brock and Taylor is based on the neoclassical Solow growth model, but with an emission function that incorporates pollution abatement, with abatement and savings rate assumed to be exogenously determined. In their study, the theoretical model indicates that growth in $CO_2$ emissions depends on the initial level of $CO_2$ emissions, saving rate, abatement intensity, population growth rate and the depreciation rate. Still, abatement is assumed to be zero in the empirical application of the model. One could replace the savings rate, population growth and the depreciation rate with output as these variables are the key factors determining output in the Solow growth model.

On the other hand, in a Ramsey type of endogenous growth model, Ordás Criado et al. (2011) make the propensity to consume and invest in clean technologies endogenous. In their model the expenditures on clean technology directly affect the capital accumulation function. Furthermore, the authors assume that the individual’s utility function is only affected by consumption per capita and pollution per capita, but with an emission function similar to that used by Brock and Taylor (2010). The final pollution growth model proposed by Ordás Criado et al. (2011) is derived from a non-linear system of equations comprising pollution per capita and capital (normalized by effective labor).

The above models assume implicitly that neither pollution nor capital dynamics are influenced by political economy variables (such as the quality of institutions), although intuitively one would expect some interaction between all of these variables. We therefore address this issue by looking at specific aspects of institutions such as government effectiveness, control of corruption, rule of law and regulatory quality by developing an index that combines these aspects of institutions. The index we develop is based on principal component analysis (PCA). This index is then included as one of the factors that potentially can influence growth in per capita $CO_2$ emissions in the model proposed by Ordás Criado et al. (2011).

## 2.2 Empirical Specification

The empirical parametric specification for growth in per capita $CO_2$ emissions is based on the theoretical model proposed in Ordás Criado et al. (2011). This model predicts a negative relationship between emission growth and emission levels (i.e., $\beta$-convergence), but this is conditional on a positive relation between emission growth and output (GDP) growth. Moreover, it is also useful to include the previous level of GDP to accommodate the effects of the higher order terms that were ignored in the Taylor series expansion of both capital and the pollution per capita systems of equations. The resulting empirical specification that is explored with panel regressions and can then be expressed as:

$$GCO_{2,it} = \alpha_0 + \alpha_1 \ln CO_{2,\mathrm{it}-T} + \alpha_2 GGDP_{it} + \alpha_3 \ln GDP_{i,t-T} + \varepsilon_{it} \quad (1)$$

Where $GCO_{2,it}$ and $GGDP_{it}$ are the growth rates of per capita carbon dioxide emissions and per capita output, respectively, while $CO_{2,it-T}$ and $GDP_{it-T}$ represent the initial levels of per capita carbon dioxide emissions and output, respectively. The random error term is represented by $\varepsilon_{it}$, and the subscripts $i$ and $t$ denotes country and time, respectively.

Since we are interested in the long term dynamics, and in order to avoid the fluctuations associated with business cycles, we employ five-year averages of $CO_2$ and *GDP* growth rates. This implies that the $CO_2$ and GDP growth rates are defined as:

$$GCO_{2it} = \frac{1}{5}\ln\left(\frac{CO_{2,it}}{CO_{2,it-T}}\right), \quad T = 5,\ t \text{ starts in 1985}$$

$$GGDP_{it} = \frac{1}{5}\ln\left(\frac{GDP_{it}}{GDP_{it-T}}\right), \quad T = 5,\ t \text{ starts in 1985}$$

This strategy reduces the risk of primarily capturing short-run adjustments around the trend rather than the long-run convergence patterns.

We extend the Ordás Criado et al. (2011) model as presented in equation (1) by including a political economy variable that we denote *POLITY*, which addresses the quality of government institutions. The augmentation with this variable is because most of the policy environment regarding $CO_2$ emissions reduction, and the decoupling of economic growth from $CO_2$ emissions, are intertwined with the political economy. Furthermore, there is plenty of empirical evidence of the influence of the political economy on output growth (e.g., Acemoglu et al., 2005), and we also want to explore the direct effect of this on $CO_2$ emissions.

The extended model, including also country and time fixed effects to control for country- and time-specific unobservable variables, can be expressed as:

$$GCO_{2,it} = \alpha_0 + \alpha_1 \ln CO_{2,it-T} + \alpha_2 GGDP_{it} + \alpha_3 \ln GDP_{it-T} + \alpha_4 POLITY_{it} + u_i + \delta_t + \upsilon_{it}, \qquad (2)$$

where *POLITY* is "quality of institutions" indicator, $\delta_t$ a time dummy to capture time-variant effects, $u_i$ is a country fixed effect and $v_{it}$ is a random error term.

The conditional $\beta$-convergence hypothesis, based on equation (2), is tested by assessing that the following holds; $\alpha_1 < 0$, $\mu_i \neq \mu$ for all $i$ and $\alpha_j \neq 0$, $j = 2, 3, 4$. If we find that $\alpha_1 < 0$, $\mu_i = \mu$ for all $i$ and $\alpha_j = 0$, then we have unconditional $\beta$-convergence

Moreover, in order to account for the possible feedback effects of per capita GDP growth and the dynamic nature of the model, we apply a system generalized method of moments (GMM) parametric approach by allowing all the right hand side variables either to be endogenous or predetermined. This approach will help solve the so called "Nickell bias" inherent in dynamic panel models with a short time period (Roodman, 2009). Moreover, as pointed out above, five-year average growth rates are used in order to avoid the issues of cyclical impacts on the convergence dynamics. Most other studies make similar assumptions (e.g., Islam, 1995). Furthermore, the system GMM approach will at least reduce possible endogenous bias since the approach uses instruments in the estimation process for the right-hand side variables that are considered endogenous or predetermined. The instrumentation is done by using lags of the endogenous and predetermined regressors in a first difference equation (Roodman, 2009). This is particularly important in our model since GDP for instance is not strictly exogenous in the emission equation.

The endogenous Green Solow Growth model indicates a positive relationship between growth in per capita $CO_2$ and per capita GDP growth, and a negative relationship between growth in per capita $CO_2$ and initial level of $CO_2$ per capita. The effect of the lagged level of GDP is expected to be positive, while the effect of the *POLITY* variable is expected to be negative.

However, institutions may have both a direct and indirect effect on emissions. The direct effect of high-quality institutions on emission growth is expected to be negative, since in many cases emission reductions tend to require strong and transparent regulatory institutions. There may, however, be an indirect effect on emission growth through the effects on GDP. Since good institutions such as rule of law, government effectiveness etc., are likely to have a positive effect on GDP growth  this may in turn lead to an increase in emissions if the existing technology cannot generate more growth in GDP with less emission per unit of GDP. Our parametric strategy allows the *POLITY* variable to have both a direct and indirect effect on the growth rate of $CO_2$ per capita. This is because GDP growth is one of the possible channels that the quality of institutions affects growth in emission.

Accounting for the indirect effect of institutions, we postulate that the indirect transmission mechanism of the effects of institutions on emissions is through the growth in GDP per capita. To be able to account for this indirect effect, GDP growth is specified as:

$$GGDP_{\mathrm{it}} = \beta_0 + \beta_1 \ln GDP_{it-T} + \beta_2 I_{it} + \beta_3 OPEN_{it} + \beta_4 POLITY_{it} + u_i + \delta_t + e_{it} \tag{3}$$

The expression in equation (3) hypothesizes that growth in per capita GDP ($GGDP_{it}$) depends on the initial level of GDP per capita ($GDP_{it-T}$), investment ($I_{it}$), growth in exports ($OPEN_{it}$) and institutional quality ($POLITY_{it}$), while $e_{it}$ is the error term which we assume not to be correlated with the error term from equation (2). [1] The latter assumption makes it possible to estimate the two equations separately, and it is reasonable within this setup of a dynamic panel with both country- and time-fixed effects to account for some of the unobservables. As such we do not expect that the remaining unobservables in the emission equation will be correlated with those in the growth equation.

Equation (3) is included to account for the effect of institutions on GDP growth to help identify the indirect effect of institutions on emissions via GDP growth based on the model developed by Dalgaard et al. (2004) and Hansen and Tarp (2001).[2] The direct effect of institutional quality on $CO_2$ per capita growth and GDP growth, respectively, is then obtained via equations (2) and (3) by taking partial derivatives with respect to the institutional quality variable, that is:

$$\frac{\partial GGDP_{it}}{\partial POLITY_{it}} = \beta_4$$ (the direct effect of institutional quality on GDP growth)

$$\frac{\partial GCO_{2,it}}{\partial POLITY_{it}} = \alpha_4$$ (the direct effect of institutional quality on $CO_2$ per capita growth)

The total effect of the institutional quality variable on $CO_2$ per capita growth is then:

$$\frac{\partial GCO_{2,it}}{\partial POLITY_{it}} + \frac{\partial GCO_{2,it}}{\partial GGDP_{it}} \times \frac{\partial GGDP_{it}}{\partial POLITY_{it}} = \alpha_4 + \alpha_2 \cdot \beta_4$$

Intuitively, we expect $\beta_4$ to be positive, $\alpha_4$ negative, and $\alpha_2$ positive. Thus, we cannot sign the total effect a priori since it depends on the relative magnitudes of the direct and indirect effects.[3]

As was mentioned already in the introduction, we specify a second model in which the linear assumption is relaxed. In this second model we employ a more flexible

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[1] We estimated the correlation coefficient between the two error terms, and it was found to be low (-0.058) and statistically insignificant at the 5% level.

[2] The model in Dalgaard et al. (2004) and Hansen an Tarp (2001) includes “aid” as an additional right-hand side variable, but this is not included in our model due to lack of data. Moreover, our analysis is based on a global sample that also includes developed countries, which generally do not receive aid. We further replace exports growth with openness (trade).

[3] The total effect of institutional quality on growth in per capita $CO_2$ emissions can be solved for by substituting equation (3) into equation (2) and arranging the terms.

nonparametric econometric approach that is robust to functional misspecification. This approach also allows for all forms of interactions between the various regressors in the model. Besides, it also relaxes the constant-parameter assumption imposed by the parametric model. The nonparametric version of the model in equation (2) can be expressed as:

$$GCO_{2,it} = G(X_{it}^{d}, X_{it}^{c}) + e_{it} \tag{4}$$

Where $G(\cdot)$ is an unknown functional form that is twice differentiable, $X^d$ is a vector of discrete variables specified and defined in equation (2), while $X^c$ is a vector of all the continuous variables in the model (i.e., $\ln CO_{2,it-T}$, $GGDP_{it}$, $\ln GDP_{it-T}$, $POLITY_{it}$).

We follow an instrumental variable (IV) approach by using $GGDP_{it-T}$ and $POLITY_{it-T}$ as valid instruments for $GGDP_{it}$ and $POLITY_{it}$ in our model; this is a way of reducing the feedback effects from the regressors in the model. Since our variables include both discrete and continuous variables, we opted for a kernel estimator with mixed regressors as proposed and developed by Racine and Li (2004), consistent with panels with a short time span relative to the individual (country) dimension. Since this estimator is well established in the nonparametric literature, we refer readers to Li and Racine (2007) for details. Equation (4) is estimated using the local linear kernel estimator proposed by Stone (1977) and Cleveland (1979), and later extended by Li and Racine (2007) to handle panel data with both continuous and discrete variables. This estimator is used in Gyimah-Brempong and Racine (2010), Ordás Criado et al. (2011), and in Karimu and Brännlund (2012). The choice of this estimator can be motivated by at least two reasons. First, it permits us to correct for boundary bias, which cannot be done with the local constant kernel estimator. Second, it achieves the same rate of convergence as the case of a truly specific parametric model when the correct relationship in the data is linear (Li and Racine, 2004), which is not the case for other kernel estimators.

Our empirical approach is thus to estimate both a parametric and nonparametric model and assess the performance of each in fitting the data using diagnostic testing techniques. The idea is not to a priori superimpose any model as the best model for the data, but rather to assess the performance of both the parametric and nonparametric approaches.

## 3. Data and Data Sources

The empirical investigations rely on a panel of 124 countries over the time period 1985-2010. In order to address the importance of institutional quality we use the World Bank's Worldwide Governance Indicators (Kauffman et al. 2009) of good governance. The Worldwide Governance Indicators are based on several hundred individual variables measuring perceptions of governance, reflecting the views of a diverse range of stakeholders, such as a large number of experts working for the private sector, NGOs, and public sector agencies, as well as household and firm survey respondents. The individual measures are assigned to categories capturing six dimensions of governance, and here we focus on four of these; Government Effectiveness, Regulatory Quality, Rule of Law, and Control of Corruption.

An unobserved components model (UCM) has been used to construct these aggregate governance indicators (see details in Kaufmann et al., 2009). The governance estimates are normally distributed with mean zero and standard deviation one (1) each year of measurement.[4] This implies that generally the scores lie between –2.5 and 2.5, with higher scores corresponding to better outcomes. The fact that the indicators are exclusively based on subjective (perceptions-based) data is however a source of criticism. Still, in many instances there are no objective measures available, or the objective measures tend to capture *de jure* governance rather that *de facto* governance (Kaufmann et al., 2009).

Concerning the other variables, $CO_2$ emissions are in metric tons per capita, GDP in constant 2005 United States dollars, the sum of exports and imports of goods and services as a share of GDP. All of them are obtained from the World Development Indicators (WDI) data base of the World Bank. We also have data on investment as a share of GDP per capita taken from Penn World Tables (PWT) 7.1. Most of the variables span from 1960 to 2010, except the institutional variables. This limited our study to start from 1985. This choice of starting year is due to data availability, especially on the institutional variables coupled with the dynamic structure of the model, instrument requirement and the five-year

[4] It can be noted that Kaufmann et al. (2006) find no systematic time-trends in a selection of indicators, thus suggesting that the time-series information in the World Bank's scores can be used.

averages adopted to capture long-run adjustment rather than short-run convergence.[5] The institutional variables actually start in 1996, which means that we have used imputed values for the years 1985 and 1990. The imputation was done using a multivariate imputation method by using GDP and the institutional variable from the International Country Risk Guide's "Quality of Government" indicator. The countries in the study, descriptive statistics, and description of the data are presented in Tables A1, A2 and A3, respectively (in the Appendix).

Furthermore, we used the four institutional variables as presented in the data section to construct the *POLITY* variable based on principal component analysis (PCA). The requirements for undertaking a good PCA is as follows; first there should be high correlation between the variables in the data in order to construct components that can adequately capture the features of the original data, and secondly one should choose the component/s with eigenvalues greater than 1.

The correlation matrix for the four institutional variables shows very high correlation that *range* from 0.89 to 0.95 (results reported in Table A4 in the appendix), implying that PCA is a reasonable approach to use in constructing our *POLITY* variable. The main results from the PCA, reported in Table 1, show that only component 1 is the appropriate component to choose to represent the four institutional variables since it is the only component with an eigenvalue greater than 1. The results also reveal that component 1 explains close to 95% of the variance of the original data, while components 2, 3 and 4 explains 3%, 1%, 1% respectively of the variables of the original institutional variables, This means that component 1 contains most of the information in the original institutional variables and therefore appropriate to use as an index for the four institutional variables. For this reason we chose component 1 to represent our polity index. The constructed index tends to explain more of the variance in government effectiveness relative to the other institutional variables, with regulatory quality being the least explained relative to the

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[5] If we instead limit our study to start from 1996 based on the available data on the institutional quality variable coupled with the five–year averages, this would result in having effectively two time periods (1996-2001) and (2001-2006), In such a setting it would not be appropriate to apply a dynamic GMM approach with instruments. Moreover, we also did not want to impute more values for the institutional variables to reduce possible bias that imputations could generate on the estimates, and for this reason we opted for a starting point in 1985. However, we also estimated our model starting from 1960 but excluded the institutional quality variable from the set of regressors. This showed no significant differences in the $\beta$-convergence parameter in relation to the model based on the 1985 starting period. These results are not reported here but are available from the authors on request.

others. However, at the same time the index explains the variance of each of variable relatively well.

Table 1: Components, Eigenvalues and Proportions explained by the components

| Component | Eigenvalue | Difference | Proportion | Cumulative |
|---|---|---|---|---|
| Component1 | 3.79 | 3.68 | 0.95 | 0.95 |
| Component2 | 0.11 | 0.06 | 0.03 | 0.98 |
| Component3 | 0.05 | 0.01 | 0.01 | 0.99 |
| Component4 | 0.04 | 0.00 | 0.01 | 1.00 |
| *Variable* | *Component loadings (component 1)* | | *Proportion explain by component 1* | |
| Government effectiveness | 0.99 | | 0.97 | |
| Regulatory quality | 0.96 | | 0.92 | |
| Rule of law | 0.98 | | 0.96 | |
| Control of corruption | 0.97 | | 0.94 | |

One caveat of using such a large data set (124 countries) is uncertainty about the quality of the data, since it includes a diverse set of countries with possiblly varying degree of data quality. The difficulty of ensuring data quality over a large set of countries tends to lead to some studies focusing on smaller samples of countries such as the OECD countries. However, despite the challenges related to data quality, a study utilizing a large and diverse sample also presents interesting findings that the small sample studies cannot provide albeit some reliability issues.

## 4. Results

The estimation procedure is in three steps and can be presented as follows. In the first step we apply the parametric method. More specifically we use the dynamic panel data (DPD) estimator on the $CO_2$ growth model as presented in equation (2), and test for conditional $\beta$-convergence. In the second step, we relax the functional specifications used in estimating the parametric model by applying a fully nonparametric approach using a mixed kernel estimator that can accommodate both continuous and discrete variables. The idea of using this estimator is to allow the data generating process to determine the functional relations and also assess if the parametric model in terms of whether the functional specification is appropriate. Furthermore, the nonparametric approach allows us to examine possible heterogeneity in the conditional $\beta$-convergence hypothesis. In the final step, we compare the two approaches to assess the likely bias associated with using a less flexible approach relative to a flexible approach. We then make our analysis and policy recommendations based on the model that fits the data generating process best. In all this our focus is on the convergence parameter and the direct effect of institutional quality. However, it is also important to estimate the indirect effects of institutional quality in order to know the direction of the total effect of institutional quality on emissions, not just the direct effect.

### 4.1 Parametric model results

$\beta$-convergence comes in two forms, conditional and non-conditional convergence. In the case of non-conditional convergence, it is assumed that countries only differ in the growth rate of emissions due to differences in their initial level of emissions, while in the conditional case other variables are allowed to influence the differences in growth rate of emissions. In this study we focus on the conditional $\beta$-convergence hypothesis, which in principle is the analogue to the conditional $\beta$-convergence in income in the economic growth literature (see Islam (2005) for a comprehensive survey). Thus, if we find a statistically significant negative value on the coefficient of ln $CO_{2,it-T}$ (i.e., $\alpha_1$ in equation (2)), it indicates the existence of $\beta$-convergence, while a significant positive value indicates divergence. Moreover, if this parameter is not significantly different from zero we cannot say anything concerning convergence or divergence.

The parametric estimates for the per capita $CO_2$ growth model are reported in Table 2. The results indicate no second-order serial correlation and the Hansen test statistic does not reject the null of over-identifying restriction confirming the suitability of the DPD estimator.

The results clearly show convergence in emissions, specifically conditional $\beta$-convergence, since the parameter estimates for the initial $CO_2$ emission level is statistically significant different from zero at the 5% significance level, and the sign is negative. This implies convergence in per capita $CO_2$ emissions across the sampled countries, with the estimated rate of the convergence parameter being approximately 4%, indicating a low convergence rate across these countries.

Previous studies such as Strazicich and List (2003), Nguyen-Van (2005), and Brock and Taylor (2010) also found low convergence rates in per capita carbon emissions across countries. Specifically, based on the $\beta$-convergence concept and within a cross sectional framework. Brock and Taylor (2010) found the rate of convergence of per capita $CO_2$ emission to vary from 0.7% to 1.2% across different specifications. However, using a panel framework (a least square dummy variable estimator), they found the rate of convergence to increase to between 9 and 10 percent. Our rate of convergence values is thus smaller than in Brock and Taylor's panel model, but slightly higher than those found in Strazicich and List (2003), as well as in Brock and Taylor's cross sectional estimates. The differences between our estimates and those of Brock and Taylor are likely due to the differences in time frame, choice of estimator and the theoretical model that the empirical analysis is based on. While the underlying theoretical model for our analysis treats savings and technology as endogenous, the model used in Brock and Taylor (2010) assumes exogenous savings and technology, while that of Strazicich and List (2003) is of an ad hoc type and their sample only contains industrial countries. Based on a sample of 21 industrialized countries for the period 1960 to 1997, Strazicich and List (2003) found a rate of convergence of per capita $CO_2$ emissions of approximately 2%.

Table 2: Estimates of conditional beta convergence.

| | (GLOBAL) | (OECD) | (NON-OECD) |
|---|---|---|---|
| Initial $CO_2$ | -0.04$^*$ | -0.04$^*$ | -0.06$^*$ |
| | (-2.29) | (-2.07) | (-2.23) |
| GDP level | 0.11$^*$ | 0.03 | 0.12$^*$ |
| | (2.49) | (1.56) | (2.60) |
| GDP growth | 0.72$^*$ | 0.73$^{**}$ | 0.32 |
| | (2.14) | (3.55) | (0.83) |
| Polity | -0.03$^*$ | -0.00 | -0.01 |
| | (-2.54) | (-0.25) | (-0.92) |
| Time Dummies | yes | yes | yes |
| *Test(P-values)* | | | |
| Hansen test | 0.08 | 0.39 | 0.04 |
| Diff-Hansen | 0.22 | 0.10 | 0.14 |
| AR1 | 0.02 | 0.03 | 0.04 |
| AR2 | 0.23 | 0.36 | 0.23 |
| Instrument Count | 44 | 31 | 42 |
| Countries | 124 | 28 | 96 |
| Observations (*N*) | 706 | 165 | 541 |

Note: We use system GMM (Blundell and Bond 1998) two step estimator to obtain the reported estimates in the above table with *t* statistics in parentheses and $^*$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$. The xtabond2 specification suggested in Roodman (2009) is applied in STATA to obtain the reported estimates; robust standard errors are used to calculate the *t*-statistics, yes implies that time dummies are included in the estimation.

Various authors find little evidence in support of $CO_2$ convergence in a global sample, but fairly strong evidence of convergence on a sample of OECD countries (see Pettersson et al., 2014). Here, however, we find evidence in support of conditional convergence in the global sample that comprises 124 countries across the world. As a robustness check on the sample, we further divided the sample into an OECD sample and non-OECD sample, and as can be seen in Table 2 the results conclusively indicate the presence of $\beta$-convergence in both the OECD and the non-OECD samples.

One interesting finding from the results is that the rate of convergence tends to differ between these two samples, with the OECD sample having a lower rate of convergence relative to that of non-OECD countries. One explanation for this could be the higher capital intensities of the former group of economies (see also Brännlund et al., 2014). For instance, capital intensive industrial sectors often possess putty-clay technologies, which provide very little short-run flexibility in terms of factor input mixes as well as emission intensities. This heterogeneity will be investigated further using the nonparametric approach.

The conclusion so far is then that there seems to be convergence in $CO_2$ emissions on both the global level and among OECD and non-OECD countries as separate groups, but also that the rate of convergence tends to be higher within the group of non-OECD countries relative to the OECD countries.

Concerning the conditioning variables in the model, the growth rate of GDP indicates a positive effect on growth in per capita $CO_2$ emissions, which is in line with our a priori prediction. The estimated parameter for per capita growth in GDP is positive and statistically significant at the 5% level, and it is also significant in economic terms as the estimated elasticity of GDP growth from the global sample is 0.77%. This shows the importance of growth in GDP in emissions dynamics, and more importantly it indicates the potential in reducing per capita $CO_2$ emissions from policies that can decouple growth in GDP from emissions. Furthermore, our results also demonstrate the potentials of technologies that allow switching from production processes that rely on polluting energy sources to less polluting sources on growth in $CO_2$ emissions. Moreover, in order to control for the effects of the state of technology, time dummies are included. The parameters corresponding to these time dummies are all significantly negative, implying that on average technological change and altered behavioral patterns have tended to reduce growth rates in per capita $CO_2$ emissions.

Concerning the institutional quality variable we find a statistically significant and negative effect on growth in per capita $CO_2$ emissions at the 5 % significance level. The implication of this result is that the index that comprises good regulatory institutions, control of corruption, government effectiveness and rule of law has a direct effect in that it tends to slow down the growth in per capita $CO_2$ emissions. Nevertheless, the total effect of institutional quality on $CO_2$ emissions could still be positive if the indirect effect via GDP growth is higher than the direct effect.

In accounting for the total effect, we postulated that one important channel that institutions can influence emissions is through GDP growth. For this reason we also estimated an economic growth model as presented in equation (3). The results from this model are reported in Table 3. Here it can be seen that *initial GDP*, *investment*, *openness* and *POLITY* are all statistically significant at the 5% level. Moreover, the results indicate positive effects of *investment* and *openness* (export growth) on GDP growth, which are consistent with economic theory. Moreover, Table 3 also shows evidence of $\beta$-convergence in GDP growth rates, both for the global sample as well as for the two sub-samples.

Table 3: Estimates of the output growth Equation.

| | (GDP Growth) GLOBAL | (GDP Growth) OECD | (GDP Growth) NON-OECD |
|---|---|---|---|
| Initial GDP | -0.254** | -0.271** | -0.561*** |
| | (-2.955) | (-3.535) | (-9.589) |
| Investment | 0.163*** | 0.340*** | 0.125*** |
| | (14.955) | (15.496) | (16.213) |
| Open | 0.005** | 0.008* | 0.010*** |
| | (3.019) | (2.391) | (7.508) |
| POLITY | 0.319*** | 0.251*** | 0.174*** |
| | (6.445) | (6.006) | (3.479) |
| *Test(P-values)* | | | |
| Hansen test | 0.049 | 0.288 | 0.183 |
| Diff-Hansen | 0.863 | 0.356 | 0.762 |
| AR1 | 0.000 | 0.142 | 0.000 |
| AR2 | 0.651 | 0.224 | 0.700 |
| Instrument Count | 86 | 30 | 86 |
| Countries | 124 | 28 | 96 |
| Observation | 701 | 166 | 535 |

The institutional quality variable (*POLITY*) has a positive direct effect on GDP growth, which is in line with the findings from previous studies in the growth literature, while this variable's direct effect on growth in $CO_2$ emission is negative. Therefore, based on the full sample, the total effect of institutional quality can be calculated as follows: $\alpha_4 + \alpha_2 \cdot \beta_4 = -0.027 + 0.715 \cdot 0.319 = 0.201$. This implies a positive total effect of institutions on growth in per capita $CO_2$ emission based on the global sample.[6] These results thus indicate that the quality of government institutions matter for the prospects for achieving sustainable growth. Institutional quality will reduce the environmental costs of higher economic growth, but it also spurs economic growth in the first place. All in all, improvements in institutional quality do thus not appear to achieve a de-linking of $CO_2$ emissions and GDP growth.

### 4.2 Nonparametric model results

One caveat of the parametric model as presented in Table 2 is that it assumes an average convergence estimate, and therefore implies that the rate of $CO_2$ emission convergence is the same across countries (and time). Additionally, it assumes a linear relationship among regressors and the dependent variable. The parametric results also indicate heterogeneity in the rate of $CO_2$ convergence when one subdivides the sample into OECD and non-OECD countries. Intuitively, however, we would expect that the rate of convergence to vary across countries, and that there exists possible interactions between the regressors. To account for the possibility of different $CO_2$ convergence rates and interactions in a flexible way, we also apply a nonparametric method that relaxes the above-mentioned restrictions imposed by the parametric model.

The main results from the nonparametric model are reported in Figures 1 and 2. Figure 1 displays the partial nonparametric fitted relationship between the growth in per capita $CO_2$ emission and each of the regressors, while Figure 2 is the gradient plot showing the estimated rates for each of the regressors in the model. Figures 1 and 2 can be read as follows. If there is a negative relationship in Figure 1 between growth in per capita $CO_2$ emissions and the initial level of emissions, then it implies evidence of conditional $\beta$-convergence. If the reverse is true we have $\beta$-divergence. In order to find the point estimates along the estimated $\beta$-convergence line, as indicated by the solid line in each of the plots in Figure 1, we estimated the gradients of the lines. The result of the latter is displayed in Figure 2, indicating the elasticity (for variables in log) or marginal effect (for variables not in log) at various points for each of the regressors in the model. Specifically, the estimated rate of $\beta$-convergence varies from -0.07 (7%) to -0.02 (2%) as the initial per

[6] Similar calculations can be made in relation to openness and investment. However these variables do not enter our emission equation directly but rather indirectly via the GDP growth equation. Since the focus of our study is not on these variables, we defer such analysis for future studies.

capita level of emissions in log terms increases from -4 to 4 (i.e., from 0.67 metric tons per capita to 1.49 metric tons per capita). The implication of this is that countries that start at lower levels of emissions tend to experience faster emissions growth relative to countries that start at a higher level of emission per capita.

As with the parametric estimates, the nonparametric results also reveal a relatively low convergence rate. However, in contrast to the parametric model, the results from the nonparametric model indicate that the rate of convergence varies with the initial level of emission per capita in the sense that those countries that start at a high level of emissions tend to have low rates of convergence, relative to countries that start at a low level of per capita $CO_2$ emissions. Again, this could in part be due to the higher capital intensities in the high-emitting countries; here further emission reductions may increasingly involve costly capital turnover in various industrial sectors.

Consistent with theory, the nonparametric estimates also result in a positive relationship between growth in per capita $CO_2$ emissions and GDP growth. This result is reported in Figure 1 (the partial regression plot) and in Figure 2 (the gradient plot). The estimated regression line between growth in per capita $CO_2$ emissions and growth in per capita GDP shows a linear relation, and the gradient plot reveals that the elasticity of GDP growth is 0.35. This value is however smaller than that found based on the parametric model. A possible reason for this difference is that in the nonparametric model, all regressors interact with each other flexibly and therefore accommodate all forms of non-linearities in the estimation process, which is not the case in the parametric model.

Furthermore, the estimated level of GDP has a positive effect on growth rates in $CO_2$ emissions as shown in Figures 1 and 2, and the bootstrap confidence bands show no departure from linearity. The positive relationship is consistent with the results from the parametric model but with a slight difference in the magnitude.

Concerning the institutional index (*POLITY*), the estimated marginal effect is negative (-0.005) but, it does not, as can be seen in Figure 2, vary across countries. This result is thus consistent with the parametric model assumption of a constant linear relationship. However, this effect is smaller in magnitude than the corresponding value in the parametric model. Again, a possible reason for this difference is the lack of interaction between the policy variables and the GDP variables in the parametric model, while such interactions are incorporated in the nonparametric model.

The conclusions one can draw from the nonparametric estimates are that there is evidence of $CO_2$ emissions convergence, and that the rate of convergence varies across countries due to differences in the initial level of $CO_2$ emissions. The variation is more pronounced among countries with very low initial levels of $CO_2$ emission relative to countries that start at a relatively high initial level of emissions. Specifically, countries with 0.03 metric ton of $CO_2$ emissions per capita tend to converge more rapidly (-0.07) relative to countries with 1.0 metric ton per capita of $CO_2$ emission (-0.04), and those with 36.6 metric ton per capita of $CO_2$ emissions (-0.02)

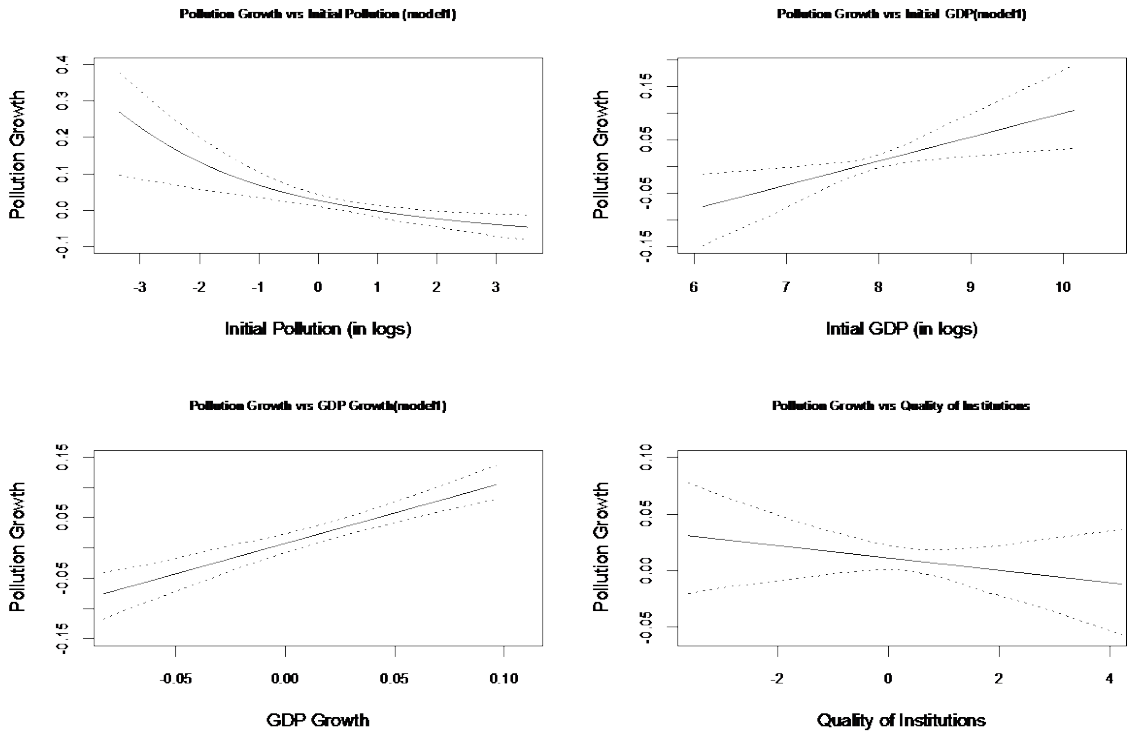


Figure 1: Partial nonparametric regressions plot of Pollution growth verses initial pollution, initial GDP, growth in per capita GDP and quality of institutions.

*Notes: The solid lines are the nonparametric fit and the dashed lines are "wild" bootstrap standard errors. The initial pollution is in metric tons per capita (logs). Y-axis is growth rates and X-axis corresponds to initial pollution, initial level of GDP, growth in per capita GDP and quality of institutions, respectively for the plots above.*

Furthermore, the results indicate that the initial levels of GDP, GDP growth and the quality of institutions do not depart from linearity but that their magnitudes are smaller than in the parametric model. Since the nonparametric model outperforms the parametric model in fitting (based on cross-validation scores) we conclude that not allowing for heterogeneity and all forms of interactions between the regressors tends to bias the estimates (absolute values) for GDP, GDP growth and the institutional quality variable. The parametric model also tends to overestimate the convergence rate for countries with higher initial $CO_2$ emissions per capita and underestimate those with lower initial $CO_2$ emissions. The implication is that the parametric model is not robust to a sample that comprises of countries that lies at the extreme ends with respect to per capita $CO_2$ emissions.

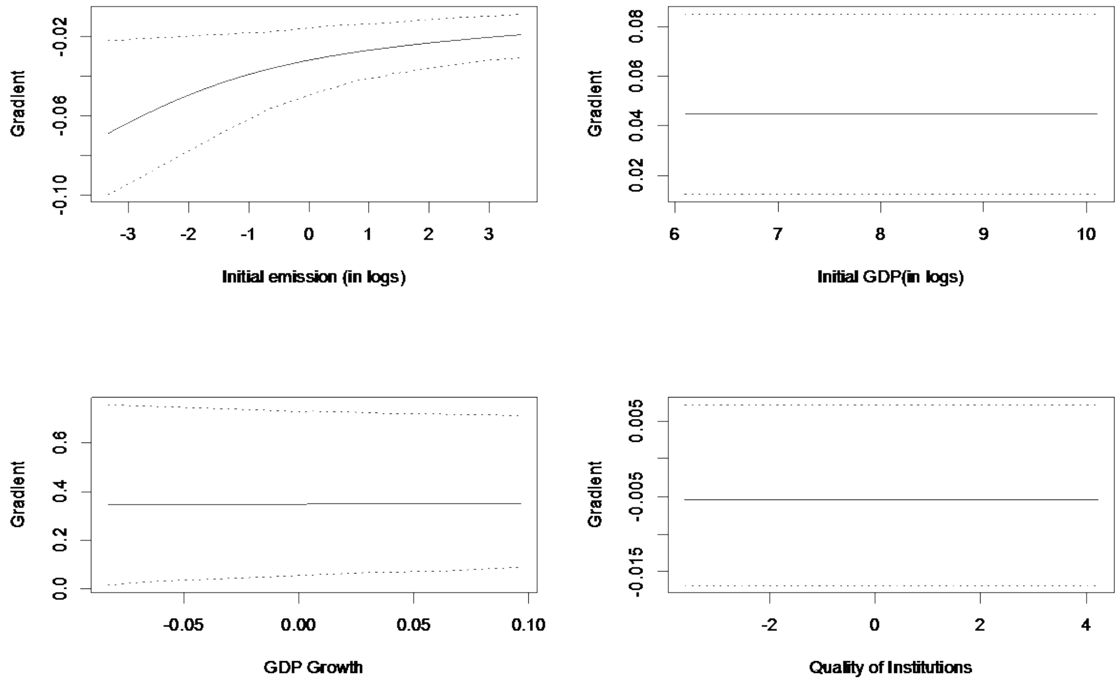


Figure 2: Nonparametric Gradient plot of conditional beta convergence, level of GDP, growth in per capita GDP and quality of institution.

*Notes: The solid lines are the nonparametric gradient line and the dashed lines are "wild" bootstrap standard errors. The gradient is estimated as* $\partial\hat{G}(x_i,\bar{x}_{i-1})/\partial x_i$ *, where* $x_i$ *is the variable of interest and* $\bar{x}_{i-1}$ *is all other variables held at their mean.*

### 4.3 Robustness check

In assessing whether the main results are robust to our choice of institutional quality index, we also estimated equations (2) and (3) by using each of the institutional variables that constitute the institutional index. The results, as reported in the appendix (Table A5), show no significant differences for all coefficient estimates, except for the individual institutional variables relative to the index. We find significant differences in the size of the estimates for the institutional variables and the coefficient estimate for the institutional index. Based on the individual institutional quality variables, we find government effectiveness, rule of law and regulatory quality to have statistically significant and negative impacts. Moreover, the results indicate no statistically significant impact of control of corruption on $CO_2$ emission growth rates. The implication of this is that various aspects of institutions may have different impacts on $CO_2$ emissions, and an aggregate index may not reveal such differences. However, whether we use an index or the individual institutional variables, the main results do not change in a profound way, especially the rate of the convergence parameter in the parametric model. Similarly, we find no significant difference in the rate of convergence based on the nonparametric model for each of the individual institutional variables except in the case of rule of law (these results are reported in Figures A3-A6 in the appendix). We can therefore conclude that the main results are generally robust to either using the index or the individual institutional variables that constitute the index.

## 5. Conclusion

This paper examined the relationship between growth in per capita $CO_2$ emissions, GDP growth, and the role of the quality of institutions within the framework of conditional beta convergence for a global sample comprising 124 countries. We based our empirical model on the dynamic endogenous growth model developed by Ordás Criado et al. (2011), which was extended by including the quality of institutions to capture the role of the political economy on emission dynamics.

We addressed our questions using both parametric and nonparametric methods, and the results indicated evidence of growth in per capita $CO_2$ emissions convergence in the global sample. This also holds when we divided the sample into OECD and non-OECD countries based on the parametric modeling approach. We also found evidence of heterogeneity in the rate of convergence; a relatively high rate for non-OECD and a lower rate for the OECD countries. Further exploring the heterogeneity in the rate of convergence, and also relaxing the linear functional specification, we applied a nonparametric approach. Also using this approach convergence continues to hold, although its rate and steady state level seems to vary between countries. The implication of this is that countries that have very low $CO_2$ emissions tend to have a different emission convergence rate (high rate) relative to those with moderate (medium rate) and higher emissions (low rate). This finding is in contrast to the majority of studies investigating the issue of $CO_2$ convergence. Most of previous studies provide seldom support to the $\beta$-convergence hypothesis in $CO_2$ emissions for global samples, but often support for $CO_2$ convergence for industrial (OECD) sub-samples (Pettersson et al., 2014). Exceptions, though, include the studies by Brock and Taylor (2010) and Nguyen-Van (2005). However, the work by Nguyen-Van only finds evidence of convergence for the global sample based on a cross-sectional analysis, but when extending the data to a panel, the author instead finds divergence of $CO_2$ emissions.

Another interesting finding from our study is that we consistently find, in both the parametric and nonparametric approach, a negative direct impact of quality of institutions on the growth in $CO_2$ emissions. Among other things this implies that having a good institutional environment, e.g., regulatory institutions that are efficient in enforcing environment policies and monitoring, is likely to reduce growth in emissions per capita relative to a poor or inefficient regulatory institution. As much as we tend to focus on environmental policies, and their impact on say $CO_2$ emission reductions, they will be less effective if the political economy environment is weak and inefficient, implying also that environmental policies are likely to be ineffective in most developing countries if efforts are not made to concurrently strengthen the quality of institutions.

It is also true, however, that good institutions can serve as “a double edged sword” having a direct negative effect on emissions, but at the same time having a positive effect on GDP growth that in turn implies an increase in emissions. It is therefore important to consider the total effect of the quality of institutions instead of just the direct effect. The political environment appears to support more GDP growth-oriented policies relative to less growth in emission, and therefore the reduction effect of the political environment on emissions tend to be low relative to the increasing effect on GDP.

Whether or not there is convergence in per capita emissions could influence the political economy of negotiating multilateral climate agreements. For instance, in the absence of convergence a per capita allocation of emission rights would result in substantial international transfers of rents (through carbon trading) or the relocation of emission-intensive industries. The rate of convergence may also play an important role in global climate policy. If the time allowed for the transition to a lower emission path is narrowed, the global economy’s capital stock will likely need to be replaced before it is worn out. As a result, overall abatement costs will increase, and in the presence of slow convergence patterns multilateral agreements may be more difficult to achieve. Our results confirm that the rate of convergence is slower for the high-emitting countries with overall higher capital intensities. The fast economic growth of some Asian and African countries, considerably increasing their capital intensities, may add to these difficulties.

## References


Acemoglu, D., Simon, J., and Robinson, J. A. (2005). Institutions as the fundamental cause of long-run growth. In Aghion, P., and Durlauf, S. N. (Eds.), *Handbook of Economic Growth*, Elsevier, North-Holland.

Aldy, J. E. (2006). Per capita carbon dioxide emissions: convergence or divergence? *Environmental and Resource Economics*, Vol. 33, pp. 533–555.

Bernauer, T., and Koubi, V. (2009). Effect of political institutions in air quality. *Ecological Economics*, Vol. 68, pp. 1355-1365.

Blundell R, Bond S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics*, 87: 115–143.

Brännlund, R., Lundgren, T., and Söderholm, P. (2014). *Convergence of carbon dioxide performance across Swedish industrial sectors: An environmental index approach*, CERE Working Paper 2014:10, Centre for Environmental and Resource Economics, Umeå University.

Brock, W. A., and Taylor, M. S. (2005). Economic growth and the environment: a review of theory and empirics, In Aghion, P., and Durlauf, S. N. (Eds.), *Handbook of Economic Growth*, Elsevier, pp. 1750–1821.

Brock, W. A., and Taylor, M. S. (2010). The green Solow model. *Journal of Economic Growth*, Vol. 15, pp. 127–153

Bovenberg, A. L., and Smulders, J. (1995). Environmental quality and pollution-augmenting technological change in a two-sector endogenous growth model. *Journal of Public Economics*, Vol. 57, No. 3, pp. 353–360.

Camarero, M., Picazo-Tadeo, A. J., and Tamarit, C. (2008). Is the environmental performance of industrialized countries converging? A 'SURE' approach to testing for convergence. *Ecological Economics*, Vol. 66, No. 4, pp. 653-661.

Camarero, M., Picazo-Tadeo, A. J., and Tamarit, C. (2013). Are the determinants of $CO_2$ emissions converging among OECD countries? *Economics Letters*, Vol. 118, No. 1, pp. 159-162.Cleveland, W. S. (1979). Robust locally weighted regression and smoothing scatter plots. *Journal of the American Statistical Association* Vol. 74, pp. 829–836.

Congleton, R. D. (1992). Political institutions and pollution control. *The Review of Economics and Statistics*, Vol. 74, No. 3, pp. 412-421.

Dalgaard C, Hansen, H., and Tarp, F., (2004). On the empirics of foreign aid and growth. *The Economic Journal*, Vol. 114, No. 496, pp. 191–216.

Dasgupta, P., Shymsundar, P., and Mäler, K-G. (2004). The economics of environmental change and pollution management: issues and approaches from South Asia. *Environment and Development Economics*, Vol. 9, pp. 9-18.

Ezcurra, R., 2007. Is there cross-country convergence in carbon dioxide emissions? *Energy Policy*, Vol. 35, pp. 1363-1372.

Fredriksson, P. G., and E. Neumayer (2013). Democracy and climate change policies: Is history important? *Ecological Economics*, Vol. 95, pp. 11-19.

Gani, A. (2012). The Relationship between Good Governance and Carbon Dioxide Emissons: Evidence from Developing Countries. *Journal of Economic Development*, Vol. 37, No. 1, pp. 77-93.

Gyimah-Brempong, K., and Racine, J. S. (2010). Aid and investment in LDCs: A robust approach, *Journal of International Trade and Economic Development.* Vol. 19, No. 2, pp. 319–349.

Hansen, H., and Tarp, F. (2001). Aid and Growth Regressions. *Journal of Development Economics,* Vol. 64, No. 2, pp. 547-570.

Islam, N. (1995). Growth empirics: a panel data approach. *Quarterly Journal of Economics*, Vol. 110, No 4, pp. 1127-1170

Karimu, A., and Brännlund, R. (2012). Functional form and aggregate energy demand elasticities: A nonparametric panel approach for 17 OECD countries. *Energy Economics*, Vol. 36, pp. 19–27

Kaufmann, D., Kraay, A., and Mastruzzi, M. (2006). *Governance Matters V: Aggregate and Individual Governance Indicators for 1996–2005*. The World Bank, Washington, DC.

Kaufmann, D., Kraay, A., and Mastruzzi, M. (2009). *Governance Matters VIII: Aggregate and Individual Governance Indicators for 1996–2008*. World Bank Policy Research Paper No. 4978, World Bank, Washington, DC.

Keeler, E., Spence, M., and Zeckhauser, R. (1971). The optimal control of pollution, *Journal of Economic Theory*, Vol.4, No. 1, pp. 19–34.

Kirkpatrick, C., and Parker, D. (2004). Regulatory Impact Assessment and Regulatory Governance in Developing Countries. *Public Administration and Development*, Vol. 24, pp. 333-344.

Lau, L-S., Choong, C-E., and Eng, Y-K. (2014). Carbon dioxide emission, institutional quality, and economic growth: Empirical evidence in Malaysia. *Renewable Energy*, Vol. 68, pp. 276-281.

Li, Q., and Racine, J. (2007). *Nonparametric Econometrics: Theory and Practice*. Princeton University Press.

Nguyen-Van, P. (2005). Distribution dynamics of $CO_2$ emissions. *Environmental and Resource Economics,* Vol. 32, No. 4, pp. 495-508

Ordás Criado, C., Valente, S., and Stengos, T. (2011). Growth and pollution convergence: Theory and evidence. *Journal of Environmental Economics and Management*, Vol. 62, No. 2, pp. 199-214.

Panopoulou, E. and Pantelidis, T. (2009). Club convergence in carbon dioxide emissions. *Environmental and Resource Economics*, Vol. 44, No. 1, pp. 47-70.

Pettersson, F., Maddison, D., Acar, S., and Söderholm, P. (2014). Convergence of carbon dioxide emissions: A review of the literature. *International Review of Environmental and Resource Economics*, Vol. 7, No. 2, pp. 141-178.

Racine, J., and Li, Q. (2004). Nonparametric estimation of regression functions with both categorical and continuous data. *Journal of Econometrics*, Vol.119, No.1, pp. 99–130.

Roodman, D. (2009). How to do xtabond2: An introduction to difference and system GMM in Stata, *Stata Journal,* StataCorp LP, Vol.9, No.1, pp.86-136

Stockey, N. L. (1998). Are there limits to growth? *International Economic Review*, Vol. 39, No. 1, pp. 1-31.

Stone, C. J. (1977). Consistent nonparametric regression. *The Annals of Statistics*, Vol. 5, No. 4, pp. 595-645.

Strazicich, M. C., and List, J.A. (2003). Are $CO_2$ emission levels converging among industrial countries? *Environmental and Resource Economics*, Vol. 24, No 3, pp. 263-271.

Van der Ploeg, F., and Withagen, C., (1991). Pollution control and the Ramsey problem, *Environmental and Resource Economics*, Vol.1, No. 2, pp. 215–236.

Westerlund, J., Basher, S.A. in press. Testing for convergence in carbon dioxide emissions using a century of panel data. Environmental and Resource Economics.

Winslow, M. (2005). Is democracy good for the environment? *Journal of Environmental Planning and Management*, Vol. 48, pp. 771-783.

## Appendix

Table A1: List of Countries for the study

| | | | |
|---|---|---|---|
| Afghanistan | Dominican Republic | Lebanon | Senegal |
| Albania | Ecuador | Liberia | Seychelles |
| Algeria | Egypt. Arab Rep. | Libya | Sierra Leone |
| Angola | El Salvador | Madagascar | Singapore |
| Argentina | Equatorial Guinea | Malawi | Somalia |
| Australia | Finland | Malaysia | South Africa |
| Austria | France | Mali | Spain |
| Bahrain | Gabon | Mauritania | Sri Lanka |
| Bangladesh | Gambia. The | Mauritius | Sudan |
| Belgium | Germany | Mexico | Swaziland |
| Benin | Ghana | Mongolia | Sweden |
| Bolivia | Greece | Morocco | Switzerland |
| Botswana | Guatemala | Mozambique | Syria |
| Brazil | Guinea | Nepal | Tanzania |
| Bulgaria | Guinea-Bissau | Netherlands | Thailand |
| Burkina Faso | Haiti | New Zealand | Togo |
| Burundi | Honduras | Nicaragua | Tunisia |
| Cambodia | Hong Kong | Niger | Turkey |
| Cameroon | Hungary | Nigeria | Uganda |
| Canada | India | Norway | United Arab Emirate |
| Cape Verde | Indonesia | Oman | United Kingdom |
| Central African Republic | Iran. Islamic Rep. | Pakistan | United States |
| Chad | Ireland | Panama | Uruguay |
| Chile | Israel | Paraguay | Venezuela. RB |
| China | Italy | Peru | Vietnam |
| Colombia | Jamaica | Philippines | Yemen. Rep. |
| Comoros | Japan | Poland | Zambia |
| Congo. Dem. Rep. | Jordan | Portugal | Zimbabwe |
| Costa Rica | Kenya | Qatar | |
| Cuba | Korea. Rep. | Romania | |
| Denmark | Kuwait | Rwanda | |
| Djibouti | Lao PDR | Saudi Arabia | |

Table A2: Summary statistics

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| $CO_2$ | 744 | 4.403872 | 6.925684 | .001733 | 63.1799 |
| GDP | 709 | 6648.238 | 7165.293 | 214.165 | 30841.6 |
| Government effectiveness | 742 | -.1091467 | .9776358 | -2.3246 | 2.337185 |
| Regulatory quality | 742 | -.1117918 | .9415471 | -2.52434 | 2.502353 |
| Rule of law | 742 | -.1754371 | .9991303 | -2.44812 | 2.505041 |
| Control of corruption | 742 | -.1372609 | 1.017456 | -2.440667 | 2.53562 |
| Investment | 744 | 22.19237 | 10.26223 | -3.923701 | 76.51 |
| Openness | 738 | 69.94752 | 49.15052 | 1.48 | 421.68 |
| Polity index | 742 | -0.091253 | 1.934305 | -4.200177 | 4.927494 |

Table A3: Variable definitions and sources

| Variables | Source |
|---|---|
| Carbon dioxide emissions per capita ($CO_2$) | Comprise carbon dioxide emissions stemming from the burning of fossil fuels and the manufacture of cement. This includes carbon dioxide produced in the consumption of solid, liquid, and gas fuels and gas flaring. Data are taken from World development indicators (WDI) and are expressed in metric tons. |
| Gross domestic product per capita (GDP) | GDP per capita is gross domestic product divided by midyear population, and it is expressed in constant 2005 US dollars (WDI). |
| Government effectiveness | Reflects perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies which is in the standard normal unit. The score ranges between -2.5 and 2.5 with higher values representing better outcomes. The Worldwide Governance Indicators (WGI, 2013) |
| Regulatory quality | Reflects perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development which is in the standard normal unit, and range between -2.5 and 2.5 with higher values representing better outcomes. (WGI, 2013) |
| Rule of law | Reflects perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence which is in the standard normal unit, and range between -2.5 and 2.5, with higher values representing better outcomes. (WGI, 2013) |
| Control of corruption | Reflects perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests which is in the standard normal unit, and range between -2.5 and 2.5, with higher values representing better outcomes. (WGI, 2013) |
| Investment | Investment share of PPP converted GDP per capita at 2005 constant prices from Penn World Tables 7.1. |
| Openness | Sum of exports and imports of goods and services express as share of GDP taken from WDI. |

Table A4: Correlation matrix for the institutional variables

| | Government effectiveness | Regulatory quality | Rule of law | Control of corruption |
|---|---|---|---|---|
| Government effectiveness | 1.0000 | | | |
| Regulatory quality | 0.9379 | 1.0000 | | |
| Rule of law | 0.9521 | 0.9149 | 1.0000 | |
| Control of corruption | 0.9430 | 0.8931 | 0.9438 | 1.0000 |

Table A5: Estimates of conditional beta convergence based on four institutional variables

| | (1) Government effectiveness | (2) Regulatory quality | (3) Control of corruption | (4) Rule of law |
|---|---|---|---|---|
| Initial $CO_2$ | $-0.0482^{*}$ | $-0.0473^{*}$ | $-0.0441^{*}$ | -0.0414 |
| | (-2.402) | (-2.319) | (-1.943) | (-1.821) |
| GDP level | $0.112^{*}$ | $0.103^{**}$ | 0.0781 | $0.101^{*}$ |
| | (2.607) | (2.848) | (1.870) | (2.191) |
| GDP growth | $0.729^{*}$ | $0.733^{*}$ | $0.784^{*}$ | $0.726^{*}$ |
| | (2.225) | (2.428) | (2.134) | (2.075) |
| Polity | $-0.0547^{**}$ | $-0.0507^{**}$ | -0.0269 | $-0.0489^{*}$ |
| | (-2.671) | (-2.833) | (-1.878) | (-2.384) |
| Time Dummies | yes | yes | yes | yes |
| | | | | |
| *Test(P-values)* | | | | |
| Hansen test | 0.108 | 0.099 | 0.069 | 0.067 |
| Diff-Hansen | 0.156 | 0.198 | 0.191 | 0.173 |
| AR1 | 0.002 | 0.002 | 0.002 | 0.002 |
| AR2 | 0.194 | 0.200 | 0.202 | 0.201 |
| Instrument Count | 93 | 93 | 93 | 93 |
| Countries | 124 | 124 | 124 | 124 |
| Observation | 701 | 701 | 701 | 701 |

Note: We use system GMM (Blundell and Bond 1998) two step estimator to obtain the reported estimates in the above table with *t* statistics in parentheses and $^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$. The xtabond2 specification suggested in Roodman (2009) is applied in STATA to get the reported estimates; robust standard errors are used to calculate the *t*-statistics.

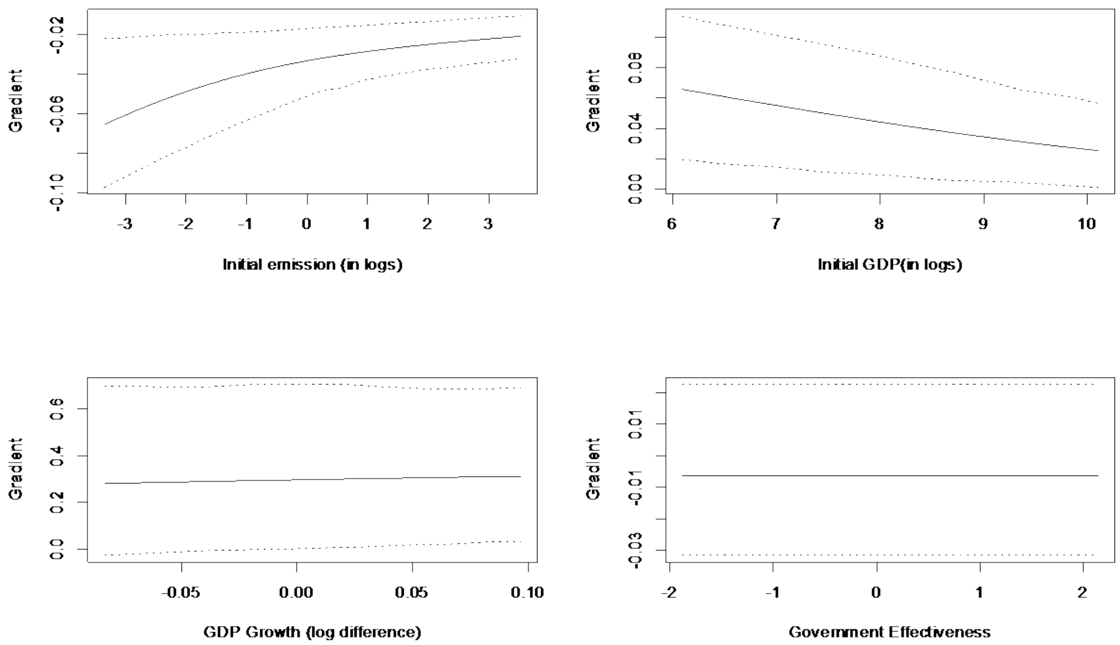


Figure A3: Gradient plot of the nonparametric model with Government effectiveness

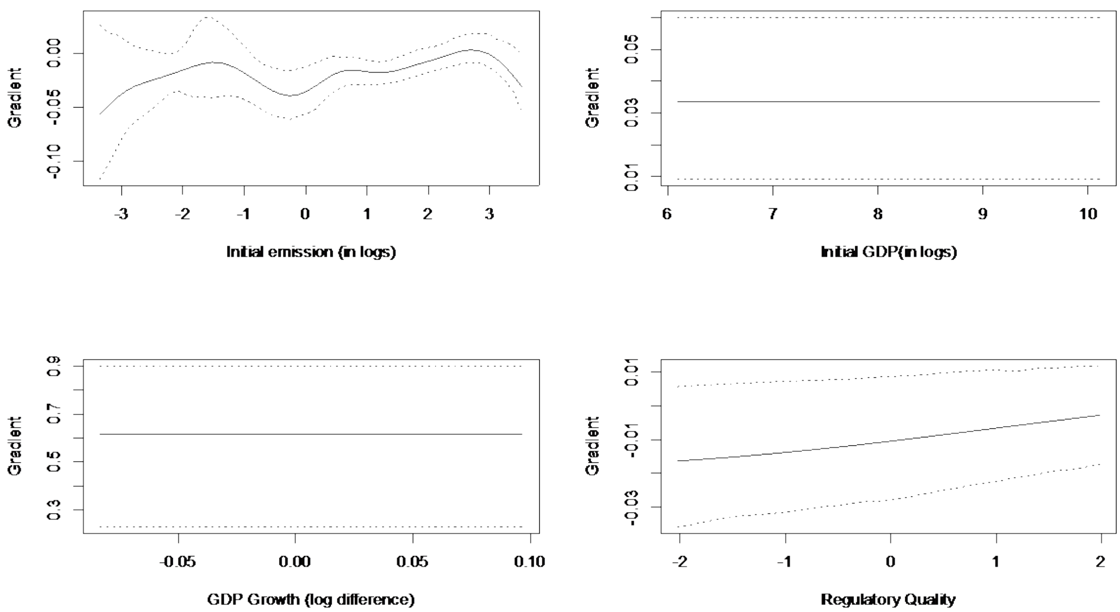


Figure A4: Gradient plot of the nonparametric model with Regulatory Quality

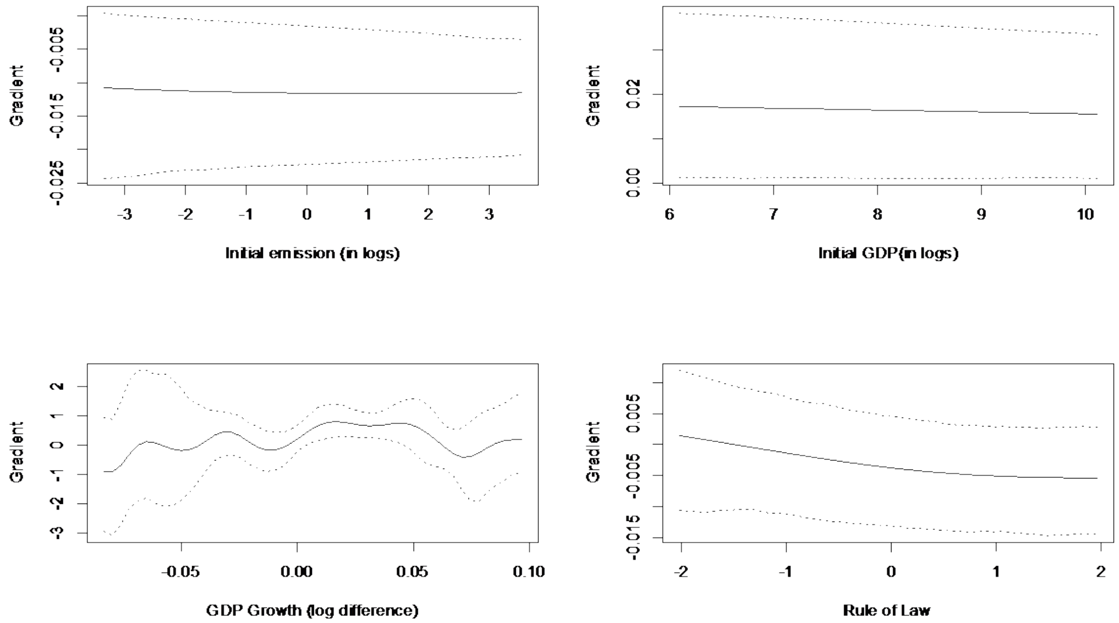


Figure A5: Gradient plot of the nonparametric model with Rule of law

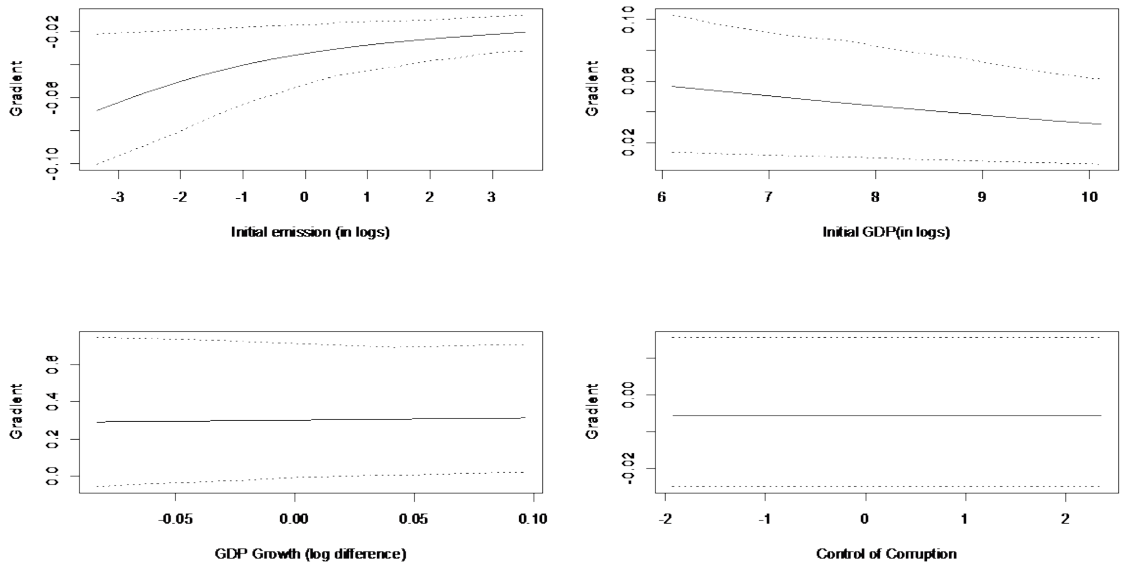


Figure A6: Gradient plot of the nonparametric model with Control of corruption