Energy Poverty through the lens of the Energy-Environmental Kuznets Curve Hypothesis

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Abstract

We revisit the concept of energy poverty by considering population's access to energy consumption. We stress critical relevant linkages including (i) economic growth and energy consumption, (ii) energy consumption and income inequality and (iii) economic growth and electricity production. Our analytical framework is based on a panel data-set from over 200 countries for the period 2000-2019. To the best of our knowledge, this is the first study to focus both on a global aggregate sample and on the differences between high and low income economies. Main findings provide support to the Energy-Environmental Kuznets Curve hypothesis. We find that, the link between economic growth and renewable energy exhibits a U-shaped curve, while that between economic growth and fossil fuel energy consumption, an inverted U-shaped curve. In addition, an increase in renewable energy consumption reduces income inequality. Furthermore, stronger economic growth positively affects electricity production from renewable sources, while it reduces electricity production from coal. Finally, results remain qualitatively similar across different levels of income, and while controlling for potential endogeneity. Findings raise important policy implications, particularly considering the impact of renewable energy on energy poverty.

Keywords: Energy poverty; Energy-Environmental Kuznets curve hypothesis; Electricity production; Energy consumption; Income inequality; Panel data; Renewable Energy

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1 Introduction

The energy sector is a sector of major importance for the global economy. It affects many aspects of economic life and is crucial for decision makers. From the standpoint of economic policy, developments in the energy sector are closely linked to discussions about growth and pollution, about promoting environmentally friendly energy sources, as well as, about energy security matters. At the same time, given the relatively recent financialisation of energy markets, developments in the energy sector also have a bearing on financial investment decisions and portfolio management. This study narrows the investigation of energy markets to a recent yet growing field of the relevant literature; that is, energy poverty, particularly focusing on the link between energy consumption and income inequality.

We are motivated by the fact that, not everyone has sufficient access to energy, especially in developing countries; which practically summarises the issue at hand. That is, energy poverty raises the question of how sufficient is access to energy sources by the population across the different countries of the world. In this regard, on one hand, energy poverty touches upon issues such as level of economic growth, income inequality, energy consumption while, on the other, it involves the different types of energy that are currently available and also the priorities of each country with regard to energy production. Therefore, in this study we purport to highlight the linkages between these aspects by considering, as we further explain below, the Energy-Environmental Kuznets Curve approach.

To put everything into perspective, authors such as Day et al. (2016) argue that the extent of energy poverty within a country could potentially be determined by the respective extent of sufficient access to affordable energy sources. In turn, access to energy sources unequivocally relates to income distribution and income inequality issues within the country. For instance, Zhang et al. (2019) focus on electricity consumption (i.e., understandably, access to sufficient electricity resources is a key determinant of the extent of energy poverty) and identify various factors such as access to finance, education and extent of economic development, all of which appear to have a positive impact on access to electricity. With reference to electricity production, Stram (2016) stresses the importance of utilising renewable energy sources for the production of electricity for eventually containing energy poverty. It would also be instructive at this point to note that, renewable electricity production refers to corporate production whereas renewable electricity consumption represents the energy delivered to the end-use sectors (see, for example, Ohler and Fetters, 2014). At the same time, authors such as (Topcu and Togcu, 2020) put forward the argument that renewable energy results in lower levels of income inequality. Therefore, in this study we bring together existing strands of the literature that relate to energy poverty, energy production, income inequality and economic growth. We highlight the importance of electricity production by considering the relative components of the latter and we also investigate how different types of energy consumption affect income inequality.

The topical character of all these issues further implies that there is a rapidly growing body of relevant research. In this respect, existing literature highlights the use of the environmental Kuznets curve (EKC) hypothesis, which is empirically tested by Grossman and Krueger (1991) and Panayotou et al. (1993), and states that there is an inverted U–shaped nexus between pollution and economic development. More specifically, the EKC hypothesis proposes that pollution begins to rise and then to fall as per capita income increases (economic growth expands). The importance to test the validity of the EKC hypothesis has been highlighted in the studies of Shahbaz et al. (2013), Apergis (2016), Churchill et al. (2018) and Churchill et al. (2020), among many others. A common ground shared by all studies is the use of pollutants, such as carbon dioxide (CO_2) or sulphur dioxide (SO_2) emissions, and testing a group of countries or a single economy by using various econometric techniques; their findings are supportive of the EKC hypothesis. In this regard, Shahbaz and Sinha (2019) provide an extensive review of the EKC literature.

Against this background, the aim of this study is to take one step further by focusing on the Energy-Environmental Kuznets Curve (henceforth, EEKC) hypothesis, which has received limited attention. More specifically, the literature in the EEKC hypothesis uses the energy consumption instead of pollutants used in the EKC hypothesis. In this respect, the EEKC hypothesis refers to an inverted U–shaped nexus between energy consumption and economic development. Specifically, the EEKC hypothesis suggests that energy consumption increases with income per capita at the early stages of economic growth and then reaches a peak for a specific threshold of income, before it starts to decline at the late stages of economic growth. This reduction is motivated by efficient energy policies to promote environmental sustainability. Relevant studies in this line of research were conducted by Luzzati and Orsini (2009), Pablo-Romero and De Jesús (2016), Pablo-Romero et al. (2017) and Shahbaz et al. (2020), among others. For example, Shahbaz et al. (2020) examine 30 Chinese provinces over the period 1980-2018 by employing a non-parametric regression analysis. They conclude that the EEKC holds between energy consumption and economic growth for 20 provinces in China. Hence, we maintain that it is important to extend the existing literature and shed more light into the EEKC hypothesis. We seek to advance the understanding of this particular area of energy economics as well as we expect to provide some evidence, which have not been examined so far in energy-related literature.

To accomplish this, we examine the relationship between economic growth and energy consumption and to further elucidate the link between energy consumption and income inequality. Specifically, we decompose energy consumption into four sub-elements, namely, electric power, fossil fuel, renewable and nuclear. In addition, we investigate the relationship between economic growth and electricity production. Similarly, we disaggregate electricity production by way of production, to six sub-components, namely, oil, coal, renewable, nuclear, natural gas and hydroelectric sources. Furthermore, we pay attention to the level of development for all countries and hence we categorise our sample to high income (including upper middle income) and low income (including lower middle income).[1]

The distinction between high income and low income countries can be justified by the view that high income countries are expected to show greater awareness to environmental quality. Indeed, high income countries are characterised by political stability, well-developed financial markets and financial institutions, trade openness, and access to quality education. This generates resources in the form of government subsidies (for instance, payment of funds for installing cleaner renewable energy operators) or technological innovations (for example, R&D activities for greater energy productivity and efficiency). In turn, such activities contribute to lower carbon emissions/levels and hence a reduction in air pollution, and consequently improve air quality. Overall, economic growth in high income countries is a key factor which promotes equal access to opportunities and thus reduces income inequality, while investments in clean energy have a valuable impact on environmental quality.

Considering the variables under investigation, we note that heterogeneous responses should be expected between high income and low income countries. For example, increasing renewable energy technology leads to climate change and a reduction in energy poverty. To this end, low income countries which have limited access to renewable energy options together with lower equal access to opportunities and /or social exclusion are not expected to support energy policies to reduce income inequality and promote welfare.

With these considerations in mind, the contribution of this paper can be described by the following points. First, we use a panel data-set, which includes over 200 economies and therefore, this can be considered as a global sample. To the best of our knowledge, this is the first study to test the EEKC hypothesis utilising a global sample. Second, we extend existing literature on the EEKC by considering different types of energy types (i.e., including renewable energy sources) and by further considering both energy consumption and energy production. Third, we examine the energy-growth relationship not only for the full sample but also by separating high from low income countries. This distinction is motivated by the view that we expect to capture heterogeneous behaviour between the two groups of

[1]The decision to merge between high and upper middle income countries on the one hand and low income and lower middle income countries on the other hand is merely attributed to technical issues. By imposing this separation, our empirical analysis does not suffer from limitations such as a small number of observations.

income. Fourth, we take into account the period since 2000 which accommodates large developments in energy poverty and biggest environmental changes. Finally, we provide core policy implications as well as discussion on how to promote this important, yet under-researched strand of literature.

The disaggregation of energy consumption and electricity production is justified by the fact that different sources of both indicators are expected to respond differently to the economic development and consequently to influence the EEKC hypothesis in a different manner. For example, we argue that economic growth is anticipated to affect positively (negatively) the energy consumption from renewable (fossil fuel) sources. In turn, this entails a U-shaped (inverted U-shaped) curve. Similar responses are expected when the electricity production is generated from renewable (oil and coal) sources. Put differently, the use of renewable energy consumption and renewable electricity production increase with the level of economic development. In contrast, the use of fossil fuel energy consumption and oil or coal electricity production falls with the level of economic expansion. We maintain that either renewable energy consumption or renewable electricity production are considered as environmental friendly sources, whereas either fossil fuel energy consumption or oil/coal electricity production are regarded as environmental pollutant sources. Overall, such disaggregation is important and reflects a step toward in understanding and explaining the said relationships.

Our main findings can be described succinctly as follows. First, economic growth affects renewable energy consumption positively and fossil fuel energy consumption negatively. Second, increased levels of renewable energy consumption reduce income inequality. In turn, economic growth exerts a positive impact on renewable electricity production and a negative impact on coal electricity production. On a parallel note, we do not observe noticeable differentiation of the results when the sample is divided into high and low income countries, although findings are rather more conclusive for high income economies. Overall, we lend support to the EEKC hypothesis.

These findings are important from an energy poverty point of view, as their main implications point towards renewable energy being the catalyst for reducing income inequality and thereby energy poverty within a country. It should be stressed that prominent among the implications of the study, is that renewable energy, although it is clearly an important factor towards the reduction of energy poverty, is not so effective during the early stages of growth. In this regard, our findings suggest that societies with higher levels of income, that have probably also achieved higher levels of education and environmental awareness, benefit more from the applications of renewable energy.

The rest of the paper is structured as follows. Section 2 presents the literature review and develops the hypotheses. Section 3 describes the data and econometric models. Section 4 presents the empirical findings and an in-depth discussion of the policy implications. Section 5 concludes the study.

2 Brief review of the literature and the theoretical background of the testable hypotheses

2.1 Brief review of the literature

A wealth of literature has investigated topics related to the energy poverty and this literature is still growing. For example, Thomson et al. (2016) argue that a reconsideration of the energy poverty definition at an EU level is important to further support the profile of energy poverty due to the concerns that raised within all EU members from 2001 onwards. According to Boardman (2013), energy poverty is related to the household income, energy efficiency and energy prices. In addition, there are older and recent attempts to measure energy poverty and indicators for monitoring projects to reduce energy poverty levels (see Pachauri and Spreng, 2011) or the determinants of energy poverty (see Moore, 2012). In this paper, we associate energy poverty with renewable energy production via access to electricity (see Palit, 2013).

Recently, Churchill and Smyth (2020) indicate ethnic diversity as a driver of energy poverty. Authors such as Welsch and Biermann (2017), Thomson et al. (2017), Rodriguez-Alvarez et al. (2019), Churchill et al. (2020), and Llorca et al. (2020) investigate the impact of energy poverty on factors such as health and well-being. Overall, with reference to the relevant studies on this research field, we notice that it is beyond the scope of this paper to provide a detailed review and thus we decided to simply underscore the key findings from the existing literature that accord with the purpose of our study.

The first strand is related to the relationship between economic growth and energy consumption. This line of research is motivated by Kraft and Kraft (1978) and includes papers by Chiou-Wei et al. (2008), Chiou-Wei et al. (2008), Apergis and Payne (2009), Apergis and Payne (2010), Joyeux and Ripple (2011), Dergiades et al. (2013), among others. In particular, the aforementioned authors examine causal relationships, which are supportive to either the conservation hypothesis, the feedback hypothesis, the growth hypothesis and the neutrality hypothesis. All hypotheses refer to uni–directional causality, bi–directional causality and no causality.[2] For example, Apergis and Payne (2009) employ a panel co-integration and error correction model for six Central American countries over the period

[2]For more information regarding the interpretation of each hypothesis and the required energy policies, we refer the reader to Antonakakis et al. (2017).

1980–2004. They report that there is short-run and long-run causality from energy consumption to economic growth which is supportive of the growth hypothesis.

The second strand is associated with the relationship between economic growth and income inequality. Relevant studies refer to authors such as Halter et al. (2014), Brueckner et al. (2015), Berg and Ostry (2017), Aiyar and Ebeke (2020). The general consensus from the aforementioned studies indicates a negative impact of income inequality on economic growth, or no impact. In addition, this relationship can be non-linear and be subject to the country's income level. For instance, Aiyar and Ebeke (2020), who employ a regression analysis for 166 countries over the years 1950 to 2015, report a negative effect of income inequality on economic growth when the opportunities measured by inter-generational mobility are not equally distributed. It should be mentioned that, this strand of the literature is closely related to the EKC hypothesis.

The third strand is focused on the relationship between economic growth and electricity production. Interestingly, this strand has received limited attention and hence it requires further research attempts. One related study which has considered this relationship includes the paper by Bento and Moutinho (2016) who investigate the validity of the EKC hypothesis in the case of Italy during 1960 - 2011 by employing the autoregressive distributed lag (ARDL) bounds model. They document that a long-run unidirectional causality relation running from economic growth to renewable electricity production and a lack of causality from economic growth to non-renewable electricity production.

As aforementioned, we build and expand the EKC hypothesis by focusing on both the energy and environmental component of the hypothesis; namely EEKC. Regarding the EKC hypothesis, the existing literature tests its validity that economic growth increases pollutants such as CO_2 or SO_2 emissions but after a certain point of economic expansion, emissions will fall. In this regard, the existing literature provides mix results associated with the inverted U-shaped and consequently the validity of the EKC hypothesis. More specifically, there are also evidence of an N-shaped or inverted N-shaped relationship between economic growth and pollutants due to changes in technology over time. This form of the EKC hypothesis supports that the fall of emissions after the certain point is followed by an indefinitely increase which is associated with a second certain point. Thus, the N-shaped curve is related to two turning points. To illustrate this, Churchill et al. (2020), and Shahbaz et al. (2013), provide evidence regarding the inverted U-shaped, whereas Bekhet and Othman (2018), Churchill et al. (2018), Shahbaz et al. (2017), and Onafowora and Owoye (2014) report mixed results. On the other hand, authors such as Ajmi et al. (2015) do not support the validity of the EKC hypothesis.

To elaborate, the relationship between energy consumption, economic growth and income inequality appears to be more complex than was expected. For instance, the relationship between renewable energy consumption and income inequality with a particular attention to the study performed by McGee and Greiner (2019) and related to Slovakia and Namibia. More specifically, the authors report that an increase in renewable energy consumption is associated with a reduction in emissions when income inequality is not considered. However, by considering income inequality, the authors document that for Slovakia (Namibia) with a low (high) income inequality, although a higher share of renewable energy sources displaces more (fewer) fossil fuels sources, income inequality begins to rise (fall). On the one hand, this implies that the attempt to expand the use of renewable energy sources generates a reduction in income inequality, however, fossil fuel systems cannot be displaced by renewable energy systems. On the other hand, this indicates that the effective use of renewable energy sources to display fossil fuel sources is not be good enough to encounter the various sources of income inequality.

2.2 The theoretical background of the testable hypotheses

In attempting to better understand the development of the testable hypotheses, we provide the theoretical channels to justify the evolution prior to and after the threshold level which accords with the theory of the EKC hypothesis. In the EKC hypothesis, there is a relationship between environmental degradation and income per capita; as income levels rise and resources become more available, industries become less environmentally destructive. Within our approach, the EEKC hypothesis adopts an analogous energy perspective.

In an attempt to support the development of our testable hypotheses, we should mention that we follow existing studies which are also tested the validity of the EKC hypothesis within the nexus of economic growth and CO_2 pollutants as well as the EEKC hypothesis within the context of economic growth and energy consumption. In this regard, an in-depth review of studies that examined the existence of the EKC and EEKC hypothesis can be found in Shahbaz et al. (2020); Papavasileiou and Tzouvanas (2021).

We initially concentrate on the connection between environmental friendly energy sources and the income per capita. In order to build our first hypothesis, a reasonable explanation can be possibly attributed to the fact that when the economy expands at the early stages, the energy sector which is associated to the renewable energy project investments is underdeveloped. However, R&D activities financed by public funds improve the profitability of the renewable energy investments over time. As the use of renewable energy sources significantly increases, the number of renewable energy investments accelerates. Overall, economic growth is of major importance for delivering the essential resources that required to develop a productive and efficient renewable energy market (see, for instance, Apergis and

Payne, 2010).

Hypothesis 1 (H1): In line with the EEKC hypothesis, economic growth and environmentally friendly energy consumption exhibit a U-shaped curve.

Further, we extent this framework to illustrate the relationship between environmentally friendly energy sources and income inequality. For the purpose of building our second hypothesis, a plausible explanation can be attributed to the fact that the initial cost to renewable projects at the early stages is relatively high because of the small number of firms which have the technological equipment and the financial capacity to generate renewable energy sources. Therefore, income groups cannot shift from the fossil fuel energy sources. Nevertheless, as time passes and government policies encourage the use of renewable projects via subsidies or tax cuts, the initial high cost is significantly reduced, and the income groups have now access to renewable sources which further leads to reductions in income inequality (see, for example, Topcu and Togcu, 2020).

Hypothesis 2 (H2): In line with the EEKC hypothesis, environmentally friendly energy consumption and income inequality exhibit an inverted U-shaped curve.

Next, we turn our attention to the expectation between economic growth and environmentally friendly electricity production. With the aim of building our third hypothesis, a plausible explanation can be found in the fact that renewable electricity production is relatively more expensive at the early stages of economic growth compared with fossil fuels electricity production. This is because the cost of funding for the installation of renewable energy systems is passing to consumers via the electricity bills. Thus, consumers need to pay the cost of subsidies which in turn decreases the incentive to consume renewable electricity. However, economic growth promotes renewable technologies which lead to higher renewable electricity production over time and consequently a reduction in the costs for income groups. Overall, economic growth is an important factor to create renewables electricity production (see, for instance, Ohler and Fetters, 2014).

Hypothesis 3 (H3): In line with the EEKC hypothesis, economic growth and environmentally friendly electricity production exhibit a U-shaped curve.

Finally, the relationships between economic growth and environmentally friendly energy consumption, income inequality and environmentally friendly energy consumption as well as economic growth and environmentally friendly electricity production are anticipated to exhibit heterogeneous responses between high and low income countries. In other words, we re-examine hypotheses 1-3 by distinguishing between high and low income countries as well as controlling for endogeneity.

A more thorough picture of the above testable hypotheses is evident in Figure 1 which depicts the EEKC hypothesis in a visual representation framework. We observe the relationships regarding the environmental friendly sources of energy consumption (i.e. renewable) and the pollutant sources of energy consumption (i.e. fossil fuel) on the one hand, and the GDP per capita and the income inequality on the other hand.

(PLEASE INSERT Figure 1 HERE)

3 Research design

3.1 Data

The sample consists of 217 economies that are reported in the World Development Indicators.[3] Our comprehensive sample also covers 20 years, from 2000 to 2019. This creates a country-year balanced panel data-set of 4,340 observations. We mention that those years are chosen because the unavailability of data creates constrains for investigating a larger sample. Also, our data period choice is motivated by the fact that the beginning of the 21st century is characterised by global efforts to mitigate both climate change and energy poverty. Lastly, we argue that covering all economies would help us establish more accurate results between high and low income countries. Table 1 summarises and describes the variables under investigation including the control variables.

(PLEASE INSERT Table 1 HERE)

Table 2 presents the descriptive statistics for the series under consideration. According to the standard deviation, the minimum and the maximum values, it is evident that electric power energy consumption is the most volatile series among the energy consumption variables which could be attributed to large irregular patterns in demand during periods of high and low usage. In addition, regarding the electricity production series, hydroelectric is the most volatile, followed by natural gas whereas renewable is the least volatile series. A plausible explanation regarding the higher and the lower variability between hydroelectric and renewable based on the fact that hydroelectric production is a more commonly source of

[3]The regression sample corresponds to 210 economics due to data for British Virgin Islands, Channel Islands, Gibraltar, Monaco, San Marino, Sint Maarten (Dutch part) and St. Martin (French part) are unavailable (see Appendix for the full list of countries).

renewable-specific sources of electricity and therefore more subject to peaks and troughs.[4]

(PLEASE INSERT Table 2 HERE)

Table 3 presents the pairwise unconditional correlation based on a linear relationship among the series under investigation. Regarding the renewable energy series, we observe that there is a weakly negative unconditional correlation between GDP per capita and renewable energy consumption. Furthermore, we report a weakly positive unconditional correlation between the GINI index and renewable energy consumption. Moreover, we notice a weakly positive unconditional correlation between GDP per capita and renewable electricity production. Overall, this preliminary test does not provide the required findings with the exception of the latter finding. Nevertheless, we point out that our purpose is to examine such relationships in a non-linear econometric framework and hence we expect to reveal a more clearer insight of these actual relationships.

(PLEASE INSERT Table 3 HERE)

3.2 Econometric Models

Having discussed the data, we now proceed with our econometric model. In this regard, this study builds upon a battery of panel data non-linear regression models. Since we test the validity of the EEKC hypothesis within three different links, we employ three model specifications.

Initially, we test the effect of GDP per capita which is expressed in logarithm form in level and its quadratic respectively ($LNGDP$ and $LNGDP^2$) on energy consumption ($Energy$) as shown below:

$$Energy_{i,t} = a_0 + a_1 LNGDP_{i,t} + a_2 LNGDP^2_{i,t} + \mathbf{X}'_{i,t}\phi + \sum_{t=2}^{T} \delta_t Year_t + e_{i,t} \quad (1)$$

According to Hypothesis 1, environmentally friendly energy consumption (e.g. renewable energy) declines with economic growth at the early stages of economic expansion and after reaching a threshold level increases. Hence, our expectation is $a_1 < 0$ and $a_2 > 0$ in Equation 1.

Next, we test the relationship between income inequality ($Gini$) and energy consumption ($Energy$) in level and its quadratic respectively ($Energy$ and $Energy^2$)

[4]It should be mentioned that renewables include biomass, geothermal, wind, solar and small hydro, whereas it does not include nuclear and large hydro (above 50MW).

as shown below:

$$Gini_{i,t} = \beta_0 + \beta_1 Energy_{i,t} + \beta_2 Energy_{i,t}^2 + \mathbf{X}'_{i,t}\phi + \sum_{t=2}^{T} \delta_t Year_t + e_{i,t} \quad (2)$$

In line with Hypothesis 2, income inequality increases with renewable energy consumption at the early stages of using this energy source and after reaching a threshold level declines. Hence, $\beta_1 > 0$ and $\beta_2 < 0$ in Equation 2.

Finally, we test whether an increase in GDP per capita would impact upon the components of electricity production (*Production*) as demonstrated below:

$$Production_{i,t} = \gamma_0 + \gamma_1 LNGDP_{i,t} + \gamma_2 LNGDP_{i,t}^2 + \mathbf{X}'_{i,t}\phi + \sum_{t=2}^{T} \delta_t Year_t + e_{i,t} \quad (3)$$

In Hypothesis 3, renewable energy production declines with economic growth at the early stages of economic expansion and after reaching a threshold level increases. Hence, $\gamma_1 < 0$ and $\gamma_2 > 0$ in Equation 3.

Where the subscripts i and t correspond to country and year respectively, $i = 1, 2, ..., n$ and $t = 1, 2, ..., T$ and $e_{i,t}$ represents the error term. It should be mentioned that in each regression, *Energy* denotes the energy consumption (from electric power, fossil fuel, renewable and nuclear sources), *Production* represents the electricity production (from oil, coal, renewable, nuclear, natural gas and hydroelectric sources) and $\mathbf{X}'$ is a vector that contains the control variables (inflation, unemployment, real interest rate and CO_2 emissions). Our control variables are factors that affect income inequality and consequently energy poverty. For example, higher inflation (see Walsh and Yu, 2012), higher unemployment (see Helpman et al., 2010), higher interest rates in the form of contractionary monetary policy (see Coibion et al., 2017) and higher carbon dioxide emissions (see Golley and Meng, 2012) are all contribute to higher energy poverty.

In this regard, we include these economic-specific variables in order to capture the omitted bias issue. This issue is arising when we omit factors that might affect the dependent variable (see Wooldridge, 2016). We also control for year fixed effects, so that the intercept parameters a_0 (β_0 *and* γ_0) are refereed to the base year (2000). Particular attention should be placed on the estimated coefficients a_1 (β_1 *and* γ_1) and a_2 (β_2 *and* γ_2) as they represent the level and quadratic coefficients.

The results are presented under the fixed/random effects models. For all different specifications, we use robust standard errors. A fixed effect model is appropriate when we focus on a specific firm characteristics (c_i) and therefore $e_{i,t} = v_{i,t} + c_i$ with $v_{i,t}$ being a time-varying error component. In other words, we control for country specific effects. A random effect model is also considered, which represents random draws from the population so that c_i allows for individual effects.

We apply the Hausman test in order to identify if the individual effects c_i are unobserved and are correlated with explanatory variables (see Baltagi, 2008). Lastly, we should note that our regressions are free from autocorrelation, multicollinearity and heteroscadacity.

4 Empirical Results

4.1 The impact of economic growth on energy consumption

Table 4 summarises the results regarding the impact of economic growth on the four different types of energy consumption at a global level. More specifically, the estimated coefficients both in level and quadratic form are significant, apart from column (4), and they also exhibit the anticipated signs. We note that, initially, there is a positive (negative) relationship between economic growth and electric and fossil fuel (renewable) energy consumption which, in the later stages of economic growth turns negative (positive). These findings are indicative of (i) the U-shaped EEKC hypothesis between economic growth and environmentally friendly energy sources and (ii) the inverted U-shaped EEKC hypothesis between economic growth and pollutant energy sources. Overall, we provide empirical evidence in supporting of the first hypothesis of the study.

The U-shaped EEKC hypothesis that describes the relationship between the level of economic growth and environmentally friendly energy sources could be indicative of the fact that a country has to reach a specific level of growth before it starts to exhibit environmental awareness and subsequently adopt respective environmental policies. This finding appears to be in line with Le et al. (2020), who point out that renewable energy policies are rather more successful for high income countries. This might also help explain the inverted U-shaped EEKC hypothesis between economic growth and fossil fuels consumption. It should be noted at this point that, in recent years global economic and environmental conditions have led national governments to more strongly consider adopting policies that promote renewable energy consumption. For example, Apergis and Payne (2010) argue that factors that played a significant role in encouraging renewable energy policies included the persistent volatility of oil prices (for instance, the period related to the Arab Spring and the political instability in the Middle East from 2011 to 2014), and the increasing concerns regarding the impact of carbon emissions on the environment.

(PLEASE INSERT Table 4 HERE)

4.2 The impact of energy consumption on income inequality

Table 5 presents results with regard to the impact of each component of energy consumption on income inequality at an aggregate global level. Results indicate that, renewable energy consumption appears to play a statistically significant role in reducing income inequality at some point along the EEKC hypothesis. In particular, although it has a positive effect on the Gini coefficient when we consider the variables in levels, the impact turns negative for the quadratic term. Results in connection with electricity, fossil fuel and nuclear energy consumption are not statistically significant. Overall, we are consistent with our second hypothesis regarding the impact from renewable energy consumption on income inequality.

Some authors have already identified that there are factors that give rise to income inequality globaly. Such factos include the globalisation of product markets, the dispersion of wages and the increased premium for skilled and/or educated workers (see, for example, Alvaredo et al., 2013; Apergis, 2015). However, our finding indicates that an additional factor that affects income inequality and contributes to decreasing levels is the use of renewable energy consumption. This finding is closely associated with the finding by authors such as (Topcu and Togcu, 2020) who provide evidence that renewable energy reduces income inequality in developed countries. Furhtermore, (Soukiazis et al., 2019) considering a sample of OECD countries opine that, renewable energy consumption is strongly interdependent with human capital development and manages to considerably improve economic welfare. In line with these authors we argue that the transition from carbon-intensive energy sources to more environmental friendly renewable-intensive sources (i.e., by adopting and promoting renewable energy policies) could be a factor which contributes to reducing income inequality.

(PLEASE INSERT Table 5 HERE)

4.3 The impact of economic growth on electricity production

Table 6 reports the findings that indicate the effect of economic growth on the six sub-components of electricity production in a global level. The evidence show that some estimated coefficients in level and quadratic form are significant and have the expected signs for coal, renewable and natural gas sources. In fact, this confirms the U-shaped (inverted U-shaped) EEKC hypothesis regarding the renewable and natural gas (coal). Therefore, the evidence are supportive to our third hypothesis. We also underline that the coefficients of the hydroelectric have signs opposite to our expectations and does not provide evidence in supporting of the EEKC hypothesis, this will be thoroughly examined in the next subsections.

A plausible explanation of the aforementioned findings can be attributed to the fact that the renewable energy share of electricity production shows a consistent growth every year. According to the IEA (2010), this share which was 18 percent in 2007 is expecting to increase in 23 percent in 2035. Factors that contribute to the increasing use of renewable sources in electricity production include government policies to provide renewable energy production tax credits and renewable energy portfolio standards. In addition to this, the increasing demand from the general public to a more environment friendly sources appears to be contributed to this rising share (see, for example, Sovacool, 2009; Apergis and Payne, 2012).

Our results are in line with other related studies that have considered this relationship, such as the papers by Ohler and Fetters (2014) and Bento and Moutinho (2016). More specifically, Ohler and Fetters (2014) examine the relationship between renewable sources of electricity production and economic growth. They suggest a short-run bidirectional relationship in which changes in economic growth have an inverse impact on renewable source of electricity generation, whereas changes in renewable source affect positively economic growth. Furthermore, Bento and Moutinho (2016) investigate the validity of the EKC hypothesis in the case of Italy and document a long-run unidirectional causality relation running from economic growth to renewable electricity production and a lack of causality from economic growth to non-renewable electricity production.

It would also be instructive at this point to note that, further research - particularly focusing on the linkage between electricity production and electricity consumption -, would be useful in order to attain a better understanding of this relationship in each country and further ascertain the extent to which production of energy actually translates into domestic consumption of energy. This would be an interesting avenue for future research relating to this present study.

(PLEASE INSERT Table 6 HERE)

4.4 The impact of economic growth on energy consumption of high and low income countries

Turning to the separation between high and low income countries, Table 7 reports the results with regard to the impact of economic growth on the four sub-elements of energy consumption. As far as high income countries are concerned, results confirm the significant impact on renewable and electricity and fossil fuel energy consumption. The estimated coefficients in level and quadratic form are also shown the anticipated signs. In addition, the coefficients of nuclear energy consumption are not statistically significant. With reference to the low income countries, our findings have anticipated sings, but are less significant. Given these responses, we observe heterogeneous responses between the two income groups. High income countries are better equipped to change their energy consumption modes across different levels of income.

Importantly, our findings indicate that economic growth encourages (discourages) the use of the environmental friendly (pollutant) sources of energy consumption. Indeed, since 2000 and until the beginning of the Great Recession (2008-2009), the global economic activity is mainly and positively influenced by the Chinese economic growth of 2006-2007 and generally the growth of emerging economies (rising demand for industrial commodities). In addition, the gradual recovery of the global economy after periods of financial turmoil (Great Recession and European debt crisis) or geopolitical uncertainty (Arab Spring) is also supportive of a stronger energy demand. In this regard, the report by Capros et al. (2013) which emphasises on the EU energy trends to 2050, makes a reference to a steady increase in GDP per capita between 2010 and 2050, whereas the highest GDP growth rate is anticipated between 2015 and 2030. In turn, this report indicates the transition from a fuel mix of energy consumption in favour of renewable energy consumption. This trend appears to be influenced by renewable energy sources policies until 2030 and emissions trading scheme policies beyond 2030.

(PLEASE INSERT TABLE Table 7 HERE)

4.5 The impact of energy consumption on income inequality of high and low income countries

We continue our analysis focusing on the effect of each component of energy consumption on income inequality of high and low income countries. Results are presented in Table 8. It is evident that our findings for the high income countries are similar to those observed in Table 5 and related to the estimated coefficients of the renewable energy consumption. We also document that electricity consumption increases inequality in high income countries. Thus, we lend support to the EEKC hypothesis. By contrast, we do not document significant responses to income inequality for the group of low income countries.

The relationship between income inequality and renewable energy consumption has been observed in the study of McGee and Greiner (2019). More specifically, the authors document the negative interaction between the two variables and further indicate that the increasing use of renewable energy consumption could be equivalent to lower emissions levels and consequently a replacement of fossil fuel energy consumption. Furthermore, the authors provide evidence related to Namibia and Slovakia in which the negative relationship does not always hold. Regarding Namibia, the installation of solar home systems and hence the increasing use of renewable energy consumption contributed to decreasing levels of income inequality. In contrast, Slovakia experienced a rise in income inequality although tax exemptions and subsidies for solar and wind power operators contributed to increasing renewable energy consumption.

(PLEASE INSERT Table 8 HERE)

4.6 The impact of economic growth on electricity production of high and low income countries

We continue the empirical analysis with the effect of economic growth on the six sub-components of electricity production concerning high and low income countries and the results are revealed to Table 9. We observe that the findings do not resemble those reported in Table 6 which is somewhat expected given that there is an expectation of heterogeneous responses. With reference to the high income countries, our findings confirm the U-shaped (inverted U-shaped) EEKC hypothesis regarding the renewable (coal) production. However, our empirical evidence does not support the theoretical background regarding the use of hydroelectric. Moreover, the coefficients regarding the natural gas appear to be statistically insignificant, while the coefficients related to the oil (nuclear) electricity production are only significant at level (quadratic) terms and thus we are unable to confirm the validity of the EEKC hypothesis to these two variables. As far as the low income countries are concerned, the estimated coefficients related to renewable are statistically insignificant, whereas those related to coal do not confirm the inverted U-shaped EEKC hypothesis. Similarly, the estimated coefficients associated with the hydroelectric do not support the U-shaped EEKC hypothesis. Furthermore, the relevant coefficients to oil and nuclear appear to be statistically insignificant, whereas those of the natural gas confirm the U-shaped EEKC hypothesis. Overall, the findings are mixed and the sample heterogeneity is partly accepted.

As regards the findings related to the high income countries, we argue that economic expansion is associated with government policies to financially support the development and deployment of renewable technologies which help to address the challenge of reducing the use of coal source in electricity production. Turning to the inverse response of large hydroelectric to economic growth for both groups of income, a plausible interpretation could be attributed to the fact that the expansion of large hydroelectric projects raises concerns against sustainable development, energy security and ecosystem protection and therefore such projects do not promote renewables (IRN, 2003). For instance, although large hydroelectric plants do not contribute to greenhouse gas emissions; however, they change the ecosystem and physical characteristic of the rivers due to the fact that the dam diverts water or creates a reservoir of water (C2ES, 2019). Therefore, economic expansion needs to guarantee that social and ecological costs from any source of electricity production must be minimised.

With reference to the significant findings of the increasing use of coal sources in electricity production for low income countries, we argue that although economic development could be used as a motivation of lower levels of coal, the needs of growing energy demand encourages the use of coal. In turn, this growing need corresponds to a higher investment in coal power stations. To this end, coal still play an important role in bringing electricity to millions of people mainly across Asia (FT, 2015). Finally, the use of natural gas appears to be rising in low income countries when economic expands. Although natural gas belongs to fossil fuel sources; however, it is considered as the cleanest burning and fastest growing fuel and can be regarded as a diversification from oil and coal (IEA, 2020). In this regard, we maintain that the use of natural gas together with coal for the low income countries can be explained by the fact that such countries cannot be diversified to a mix energy sources of electricity production compared with high income countries. This plausible interpretation is further amplified by the fact that oil and renewables do not respond significantly to economic development which supports the fact that low income countries have a much less diversified mix of electricity production sources.

(PLEASE INSERT Table 9 HERE)

4.7 Endogeneity

In addition, the problem of endogeneity, which has been reported continuously, should be carefully considered (Youssef et al., 2016). Endogeneity arises due to simultaneity or omitted variable bias. For example, it might be the energy consumption that drives GDP to higher levels.

A system of generalized method of moments (Sys-GMM), which is proposed by Blundell and Bond (1998), can control for endogeneity in our estimations. Hence, our previous estimations are now tested in a dynamic panel model setting:

$$Y_{i,t} = \theta_0 + \theta_1 Y_{i,t-1} + \theta_2 Z_{i,t} + \theta_3 Z^2_{i,t} + +\mathbf{X}'_{i,t}\phi + \sum_{t=2}^{T} \delta_t Year_t + e_{i,t}, \qquad (4)$$

the equation 4 is instrumented with lagged and first-difference values of the explanatory variables. Y denotes the dependent variable (i.e $Energy$, $Gini$ and $Production$) and Z and Z^2 mirror the Kuznets curve hypothesis (e.g $LNGDP$ and $LNGDP^2$). The description of $\mathbf{X}'$ is in line with the information provided in Section 3.2 while the description of $e_{i,t} = v_{i,t} + c_i$ is referred to the typical fixed effects components of the error term, with the assumption that $E(v_{i,t}) = E(c_i) = E(v_{i,t}c_i) = 0$, for $i = 1, .., N$ and $t = 2, .., T$.

In order to satisfy the orthogonality condition, we collapse instruments as proposed by Roodman (2009), this is because large number of instruments would lead to finite sample bias. Also, Hansen's test, which measures the validity of instruments, is reported as well as we test for first and second order autocorrelation. The Sys-GMM is based on two-step estimations (Windmeijer, 2005).

Our empirical analysis concludes by re-examining the three hypotheses controlling for endogeneity with system GMM estimations. Tables A.1, A.2 and A.3, in the Appendix of the study, present results based on equation 4. It is worth noting that it is important to satisfy the GMM conditions. First, there is first order auto-correlation (AR(1) p-value), but not a second order auto-correlation (AR(2) p-value). Second, our over-identifying restrictions are valid for all models (see Hansen p-value). The auto-regressive terms ($Y_{i,t-1}$ and $Gini_{t-1}$) are positive for all models. We provide evidence that our results remain qualitatively similar to those reported in the previous estimations. Indeed, sys-GMM results confirm all testable hypotheses. It should be mentioned that controlling for endogeneity, we can observe some variation on the results. In this regard, we report that hydroelectric exhibits a U-shaped relationship with economic growth which is not in line with the inverted U-shaped relationship finding from the previous estimations. It follows that this variable does not behave in a similar manner within the two previous frameworks and hence it is important to consider further analysis as future research in the contribution of hydroelectric consumption to economic growth.

4.8 Some further remarks

This paper has validated the EEKC hypothesis for a panel of countries. In this section, we provide core implications, and opportunities to extend our approach in a more articulated framework. Our results do provide clear guidance on not only promoting renewable energy policies but also focusing on the economic growth. However, focusing on economic growth is trivial. Economic growth might stem from other geopolitical, social, cultural and macroeconomic factors, which warrant further attention.

The evidence of the paper suggests that economic growth, energy consumption, income inequality and electricity production are key elements for decisions in policy making and investment. Therefore, our findings provide important economic and environmental implications for policy makers. Indeed, policy makers should carefully consider the positive consequences generated from renewable sources for the society. Increased use of renewable energy consumption reduces income inequality. Policy makers should recognise the opportunities for reducing inequality in the country by considering renewable energy in their economic planning. Promoting renewable energy could be a useful tool in achieving equal and balanced growth. In this respect, policy makers need to offer appropriate incentives for the development of renewable energy applications in both the public and the private sector. For example, such policies could include the implementation of tax credits, the provision of funding for the installation of renewable energy systems and the establishment of markets for renewable energy certificates. Similarly, the imposition of carbon taxes motivates greenhouse gas emissions reductions (see, for example, Apergis and Payne, 2010, 2011, 2012). In addition, our findings highlight the positive impact of economic growth on renewable energy consumption and renewable electricity production. Therefore, policy makers must consider technological improvements via the availability of resources to invest in research and development activities and innovation as well as the infrastructure development projects.

On a different note, given that our findings are supportive of the EEKC hypothesis, we point out that either at the global level or when we separate between high and low income groups, a certain level of income is required for all countries to achieve the transition to a low carbon economy. Obviously, this certain level is more easily attainable for the high income countries which is evident in our findings as they are more consistent to the validity of the EEKC hypothesis compared with the low income countries. Therefore, the U-shaped impact of income on the renewable energy is attributed to the fact that high income countries have already achieved higher levels of economic development.

To be more explicit, although the initial cost of gradually shifting from fossil fuels to renewables is relatively high even for developed economies due to the higher costs of capital and consequently risks required for initial projects created in new resources, the economic growth of developed economies is crucial. In this regard, economic development reveals social and economic progress in the form of advanced financial markets, availability of economic opportunities, education and health as well as lack of corruption and strong governance. Therefore, economic growth in developed countries guarantees the expansion of renewable energy sources via economic and regulatory policies in the renewable energy industry. In turn, the increasing share together with a lower cost in the long run as well as the efficient use of renewable energy sources is expected to benefit the economy in terms of lower environmental concerns and income inequality due to the access to lower income groups.

In the same line of reasoning, Churchill et al. (2021), Topcu and Togcu (2020) and McGee and Greiner (2019) have also investigated the link between renewable energy and income inequality with a particular attention to developed economies. Along similar lines, studies that concentrate on developed economies and related to corruption (institutional quality) and climate factors and their impact on economic growth include Arminen and Menegaki (2019); Stern et al. (2017); Cadoret and Padovano (2016) and Stern (2012). The quality of education also plays an important role on economic growth through the increase in human capital and the innovative capacity of the economy (see, for instance Hanushek and Woessmann, 2010).

With regard to the low income countries, we argue that they need to promote this economic development in order to reach a certain level of growth and hence to obtain the advantages of the renewable energy, which is indicated by the EEKC hypothesis. However, our results document that the use of renewable energy sources does not reduce the income inequality in this income group. Therefore, we suggest that the energy-growth nexus could be possibly associated with different unobserved factors. For example, the adoption of policies related to education in order to stimulate the environmental awareness of the population might play a crucial role in this investigation (see, for instance, Glaeser et al., 2007; Papaioannou and Siourounis, 2008; Bruns and Ioannidis, 2020). Or probably, the culture (e.g. Hofstede's cultural dimensions) might be associated with our environmental sensitivity (Pelau and Pop, 2018). Furthermore, policies to reduce corruption are required since corruption limits the availability of funds (decrease FDI inflows) to the low income groups programs through the lower tax revenues (see Apergis et al., 2012; Arminen and Menegaki, 2019). The authors in the latter studies also indicate the importance of implementing policies to encourage economic freedom or reducing the size and scope of government. Lastly, Acemoglu et al. (2019) shows that democratic nations can increase their income significantly, which can eventually shape the perceptions of the population towards the environment.

5 Conclusion

In this study we investigate the validity of the EEKC hypothesis by emphasising on three areas of the related literature, namely, economic growth and energy consumption, income inequality and energy consumption, as well as economic growth and electricity production with aim to contribute to the limited attempts on this field. In this regard, we concentrate our attention not only in global level but also in separating between high and low income countries in order to test whether consistent or heterogeneous responses can be observed. To this end, we employ panel data regressions in a global panel of over 200 countries covering the period 2000-2019. To the best of our knowledge this is the first study which examines such relationships at a global sample.

Our key findings are briefly summarised as follows. First, economic growth exerts a positive impact on renewable energy consumption and a negative effect on fossil fuel energy consumption. Second, increasing renewable energy consumption leads to a reduction in income inequality. Third, economic growth tends to exercise a positive impact on renewable electricity production and a negative effect on coal electricity production. Results are consistently supportive to the EEKC hypothesis in a global level. Finally, we do not obtain noteworthy differentiated findings when we divide the sample, although more consistent for the high income countries.

A promising area for future research within the framework of this study includes the identification of the relationship between energy policy and energy sources mix. To this end, the interrelationship between renewable energy (environmentally friendly sources) and non-renewable energy (environmental pollutant sources) indicates that both energy sources are vital for economic development which implies that economic growth is supportive to both energy sources. Therefore, the transition to more environmentally friendly renewable-intensive sources requires the enlargement of the renewable energy sector which in turn entails continuous government and regulatory policies to financially support and monitor the progress of energy efficiency based on renewable energy sources. Further research could investigate the role of international trade in energy production and energy consumption. Specifically, to test whether macroeconomic variables such as trade openness promote renewable energy production and consumption. This is because trade openness could be regarded as a factor that contributes to economic growth by accelerating investment and technological progress. In turn, this implies that more sustainable and innovative projects will be implemented to increase the share of renewable energy production in the economy, while all income groups will be able to have access to renewable energy consumption.

Finally, additional extensions of this study may include the examination of the aforementioned relationships in a Panel Vector Autoregression (PVAR) framework proposed by Holtz-Eakin et al. (1988) which allows for panel impulse response function analysis. Specifically, the advantage to employ this approach is the ability to capture the endogeneity issue by considering the variables under investigation as endogenous. Furthermore, a generalised PVAR (see, for example, Koop et al., 1996; Pesaran and Shin, 1998) can be used to address the identification scheme by switching from a Cholesky scheme to a scheme not determined from the ordering of the variables. Also, a firm-level analysis between renewable energy use and economic performance might be an interesting avenue for future research. Lastly, as discussed in Section 4.8, we call for future studies to address the role of different social, economic and political factors in order to re-validate the EEKC hypothesis.

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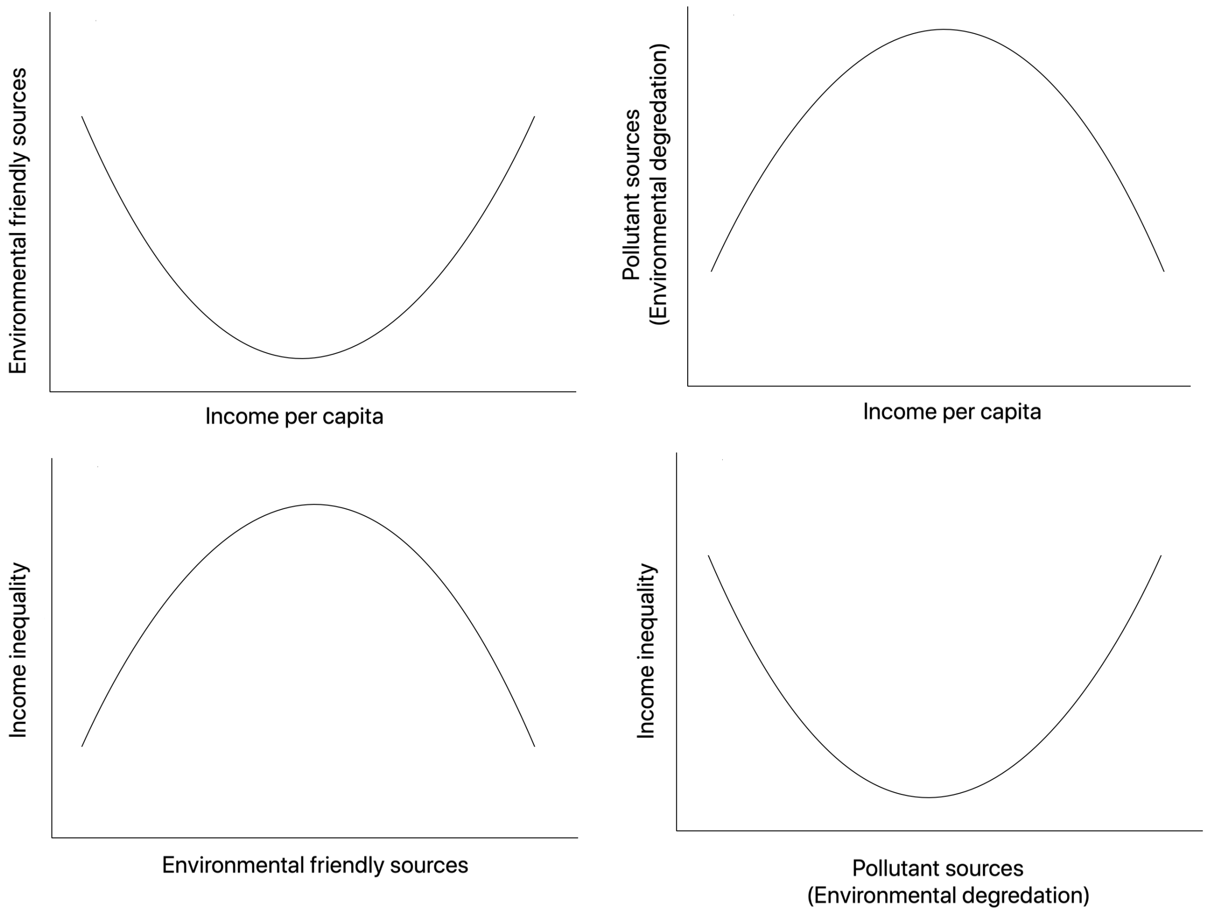
Figure 1: The Energy-Environmental Kuznets Curve hypothesis framework



Note: The first row represents the U-shaped (inverted U-shaped) curve between environmental friendly (pollutant) energy consumption and GDP per capita. The second row depicts the inverted U-shaped (U-shaped) curve between environmental friendly (pollutant) energy consumption and income inequality.

Table 1: Description of Variables

Variable Abbreviation	Description
LNGDP	Natural logarithm of GDP per capita (current $ US)
ELCON	Natural logarithm of Electric power consumption (kWh per capita)
FFCON	Fossil fuel energy consumption (% of total)
RECON	Renewable energy consumption (% of total)
ANCON	Alternative and nuclear energy consumption (% of total)
GINI	GINI index. Higher values correspond to higher inequality
OILPROD	Electricity production from oil sources (% of total)
COALPROD	Electricity production from coal sources (% of total)
NUCPROD	Electricity production from nuclear sources (% of total)
RENPROD	Electricity production from renewable sources (% of total)
HYDPROD	Electricity production from hydroelectric sources (% of total)
NATPROD	Electricity production from natural gas sources (% of total)
INFL	Inflation, consumer prices (annual %)
UNEMP	Unemployment, total (% of total labour force)
RIR	Real interest rate (%)
LNCO2	Natural logarithm of CO2 emissions (kilotones)

Note: All data have been collected from the World Bank website.

Table 2: Descriptive Statistics

Variable	Obs	Mean	Median	SD	Min	Max
LNGDP	3879	8.473	8.423	1.601	4.717	12.151
ELCON	2110	7.457	7.711	1.539	3.125	10.911
FFCON	2194	64.507	74.296	30.886	0	100
RECON	3368	30.025	18.632	30.106	0	98.342
ANCON	2126	7.301	2.782	10.326	0	55.576
GINI	1273	37.724	35.8	8.685	23.7	64.8
OILPROD	2239	17.975	2.99	28.151	0	100
COALPROD	2239	17.246	0.293	26.318	0	100
NUCPROD	2132	5.845	0	14.644	0	82.239
RENPROD	2,239	3.45	0.361	6.882	0	65.443
HYDPROD	2,239	28.924	13.275	32.257	0	100
NATPROD	2,239	25.014	12.429	31.078	0	100
INFL	3463	5.741	3.376	15.4	-60.49	513.906
UNEMP	3740	7.978	6.337	6.007	0.091	37.25
RIR	2506	6.677	5.579	11.434	-60.781	252.115
LNCO2	3033	9.028	8.954	2.59	1.992	16.146

Note: See Table 1 for each variable description.

Table 3: Pairwise Correlations

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
LNGDP (1)	1															
ELCON (2)	0.538	1														
FFCON (3)	0.252	-0.215	1													
RECON (4)	-0.371	0.082	-0.933	1												
ANCON (5)	0.222	0.437	-0.393	0.143	1											
GINI (6)	-0.215	-0.325	-0.182	0.327	-0.271	1										
OILPROD (7)	-0.120	-0.172	0.067	0.043	-0.371	0.183	1									
COALPROD (8)	0.179	0.034	0.312	-0.295	-0.194	-0.134	-0.224	1								
NUCPROD (9)	0.273	0.128	0.077	-0.356	0.546	-0.423	-0.269	0.166	1							
REPROD (10)	0.325	0.486	-0.349	0.251	0.178	-0.009	-0.019	-0.084	-0.075	1						
NATPROD (11)	-0.034	-0.107	0.458	-0.416	-0.387	-0.240	-0.225	-0.183	-0.083	-0.179	1					
HYDPROD (12)	-0.203	0.036	-0.623	0.638	0.455	0.355	-0.217	-0.496	-0.277	0.069	-0.460	1				
INFL (13)	-0.293	-0.107	-0.003	0.033	-0.122	0.006	0.034	-0.171	-0.120	-0.099	0.180	0.018	1			
UNEPM (14)	-0.028	-0.054	0.115	-0.101	0.151	0.013	-0.146	0.204	0.027	-0.159	-0.193	0.124	-0.008	1		
RIR (15)	-0.201	-0.107	-0.292	0.304	0.180	0.335	-0.049	-0.206	-0.111	-0.003	-0.298	0.480	-0.205	0.115	1	
LNCO2 (16)	0.344	0.001	0.487	-0.476	-0.233	-0.096	-0.229	0.428	0.235	-0.086	0.276	-0.476	-0.042	-0.163	-0.259	1

Note: See Table 1 for each variable description.

Table 4: Full sample: Regressions on energy consumption

	(1) ELCON	(2) FFCON	(3) RECON	(4) ANCON
LNGDP	0.332***	7.219***	-6.101***	0.479
	(0.0584)	(1.228)	(1.225)	(0.682)
$LNGDP^2$	-0.0147***	-0.451***	0.314***	0.0218
	(0.00375)	(0.0787)	(0.0767)	(0.0438)
INFL	-0.0000655	0.0104	-0.0185	-0.0000275
	(0.000606)	(0.0125)	(0.0138)	(0.00715)
UNEMP	0.00259	-0.0282	0.00898	0.0775***
	(0.00215)	(0.0442)	(0.0480)	(0.0251)
RIR	-0.00115**	0.00364	-0.0134	0.0104*
	(0.000528)	(0.0106)	(0.0110)	(0.00616)
LNCO2	0.315***	9.489***	-9.887***	-2.384***
	(0.0225)	(0.468)	(0.464)	(0.263)
Cons	2.338***	-57.36***	153.8***	25.44***
	(0.282)	(5.770)	(5.552)	(3.309)
Time dummies	Yes	Yes	Yes	Yes
Hausman test (χ^2)	47.16***	613.44***	887.47***	133.87***
Obs	1,300	1,344	1,760	1,296
R^2	0.522	0.328	0.324	0.096

Notes: Description of the variables can be found on Table 1. This table reports the results of the regressions based on Equation 1. Robust standard errors are reported in parenthesis. Asterisks ***,**,* denote the 1%, 5%, 10% significance levels, respectively. Significant Hausman test indicates that fixed effects model is preferred, random effects otherwise.

Table 5: Full sample: Regressions on income inequality

	(1) GINI	(2) GINI	(3) GINI	(4) GINI
ELCON	2.984			
	(2.838)			
$ELCON^2$	-0.294			
	(0.195)			
FFCON		0.0416		
		(0.0762)		
$FFCON^2$		-0.000712		
		(0.000610)		
RECON			0.139***	
			(0.0524)	
$RECON^2$			-0.00113**	
			(0.000561)	
ANCON				0.0552
				(0.114)
$ANCON^2$				-0.00326
				(0.00277)
INFL	-0.0227	-0.0235	-0.0243	-0.0219
	(0.0221)	(0.0219)	(0.0214)	(0.0223)
UNEMP	0.149***	0.154***	0.147***	0.134**
	(0.0571)	(0.0576)	(0.0532)	(0.0576)
RIR	0.0195	0.0182	0.0116	0.0245
	(0.0177)	(0.0175)	(0.0162)	(0.0182)
LNCO2	-0.0491	-0.0384	0.0986	-0.456
	(0.407)	(0.440)	(0.316)	(0.365)
Cons	34.07***	40.61***	35.96***	44.13***
	(9.758)	(3.859)	(3.712)	(4.042)
Time dummies	Yes	Yes	Yes	Yes
Hausman test (χ^2)	1.96	0.86	10.65	7.56
Obs	556	560	619	555
R^2	0.206	0.0824	0.173	0.112

Notes: Description of the variables can be found on Table 1. This table reports the results of the regressions based on Equation 2. Robust standard errors are reported in parenthesis. Asterisks ***,**,* denote the 1%, 5%, 10% significance levels, respectively. Significant Hausman test indicates that fixed effects model is preferred, random effects otherwise.

Table 6: Full sample: Regressions on electricity production

	(1) OILPROD	(2) COALPROD	(3) NUCPROD	(4) RENPROD	(5) NATPROD	(6) HYDPROD
LNGDP	0.656	3.804**	0.425	-2.856***	-13.11***	10.88***
	(3.531)	(1.677)	(0.873)	(0.958)	(3.447)	(2.598)
$LNGDP^2$	-0.168	-0.245**	0.0656	0.113*	0.733***	-0.504***
	(0.227)	(0.107)	(0.0561)	(0.0616)	(0.222)	(0.167)
INFL	-0.144***	0.0249	-0.00313	-0.00947	0.0943***	0.0438
	(0.0366)	(0.0176)	(0.00906)	(0.00994)	(0.0358)	(0.0270)
UNEMP	0.0135	-0.0409	0.0672**	0.0904**	-0.142	0.0313
	(0.130)	(0.0618)	(0.0322)	(0.0353)	(0.127)	(0.0958)
RIR	-0.125***	0.00799	-0.00668	-0.0255***	0.0324	0.105***
	(0.0319)	(0.0154)	(0.00789)	(0.00867)	(0.0312)	(0.0235)
LNCO2	6.796***	2.828***	-0.772**	-2.845***	3.126**	-8.627***
	(1.360)	(0.583)	(0.336)	(0.369)	(1.328)	(1.001)
Cons	-40.76**	-25.97***	4.436	45.56***	45.86***	66.76***
	(17.08)	(8.200)	(4.221)	(4.635)	(16.67)	(12.57)
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Hausman test (χ^2)	24.25	34.44**	11.57	8.37	2.63	3.69
Obs	1,300	1,300	1,300	1,300	1,300	1,300
R^2	0.102	0.109	0.031	0.279	0.100	0.130

Notes: Description of the variables can be found on Table 1. This table reports the results of the regressions based on Equation 3. Robust standard errors are reported in parenthesis. Asterisks ***,**,* denote the 1%, 5%, 10% significance levels, respectively. Significant Hausman test indicates that fixed effects model is preferred, random effects otherwise.

Table 7: Low vs High income countries: Regressions on energy consumption

	High income				Low income			
	(1) ELCON	(2) FFCON	(3) RECON	(4) ANCON	(5) ELCON	(6) FFCON	(7) RECON	(8) ANCON
LNGDP	0.617***	12.07***	-7.877***	-0.251	-0.139	6.063*	-3.336	-3.306*
	(0.0895)	(2.195)	(2.101)	(1.286)	(0.201)	(3.526)	(3.319)	(1.700)
$LNGDP^2$	-0.0326***	-0.737***	0.362***	0.0857	0.0187	-0.378	0.228	0.250**
	(0.00552)	(0.134)	(0.125)	(0.0785)	(0.0142)	(0.250)	(0.234)	(0.120)
INFL	-0.00128	0.00293	-0.0362*	0.00522	0.00113	0.0224	-0.00698	-0.00538
	(0.000814)	(0.0204)	(0.0209)	(0.0122)	(0.00102)	(0.0179)	(0.0194)	(0.00865)
UNEMP	0.000969	-0.0423	-0.0362	0.0862***	0.0203***	0.253**	0.145	0.0111
	(0.00205)	(0.0494)	(0.0514)	(0.0295)	(0.00713)	(0.124)	(0.114)	(0.0598)
RIR	-0.00136**	0.00699	-0.0215	0.0234***	0.000105	-0.0000136	-0.00212	-0.0113
	(0.000567)	(0.0139)	(0.0142)	(0.00828)	(0.00119)	(0.0193)	(0.0180)	(0.0101)
LNCO2	0.381***	9.556***	-7.789***	-2.366***	0.244***	9.476***	-11.16***	-1.323***
	(0.0272)	(0.517)	(0.669)	(0.320)	(0.0410)	(0.699)	(0.712)	(0.314)
Cons	1.102**	-73.89***	137.0***	27.87***	3.206***	-70.30***	160.6***	27.91***
	(0.447)	(10.36)	(10.30)	(6.271)	(0.797)	(13.98)	(12.26)	(6.508)
Time dummies	YES	YES	YES	YES	YES	YES	YES	YES
Hausman test (χ^2)	77.8***	2.58	42.76**	19.49	4.88	8.08	126.83***	4.35
Obs	892	901	1035	891	408	443	725	405
R^2	0.0879	0.298	0.0827	0.0462	0.183	0.381	0.138	0.0195

Notes: Description of the variables can be found on Table 1. This table reports the results of the regressions based on Equation 1. High and low income sample is based on the classification of the World Bank. Robust standard errors are reported in parenthesis. Asterisks ***,**,* denote the 1%, 5%, 10% significance levels, respectively. Significant Hausman test indicates that fixed effects model is preferred, random effects otherwise.

Table 8: Low vs High income countries: Regressions on income inequality

	High income				Low income			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	GINI	GINI	GINI	GINI	GINI	GINI	GINI	GINI
ELCON	-18.72***				10.27			
	(4.609)				(7.259)			
$ELCON^2$	0.881***				-0.820			
	(0.273)				(0.591)			
FFCON		0.0970				-0.165		
		(0.0971)				(0.163)		
$FFCON^2$		-0.000451				0.000976		
		(0.000748)				(0.00143)		
RECON			0.201***				0.0521	
			(0.0594)				(0.107)	
$RECON^2$			-0.00210***				-0.000136	
			(0.000729)				(0.00101)	
ANCON				-0.0838				-0.0844
				(0.122)				(0.334)
$ANCON^2$				0.00342				-0.00191
				(0.00304)				(0.00674)
INFL	-0.0303	-0.0313	-0.0243	-0.0312	-0.0230	-0.0311	-0.0369	-0.0165
	(0.0196)	(0.0195)	(0.0198)	(0.0196)	(0.0727)	(0.0699)	(0.0606)	(0.0706)
UNEMP	0.128***	0.118**	0.136***	0.131**	-0.132	-0.0328	0.137	-0.0478
	(0.0495)	(0.0525)	(0.0498)	(0.0519)	(0.234)	(0.235)	(0.146)	(0.237)
RIR	0.000381	-0.00853	0.00407	-0.00921	0.141**	0.139**	0.0390	0.148**
	(0.0154)	(0.0154)	(0.0156)	(0.0160)	(0.0600)	(0.0576)	(0.0418)	(0.0586)
LNCO2	0.576	-3.044***	-0.221	-2.318***	-0.594	0.802	0.160	-0.155
	(0.482)	(1.027)	(0.434)	(0.818)	(0.746)	(0.919)	(0.504)	(0.764)
Cons	125.2***	68.33***	39.02***	65.20***	14.98	36.61***	36.30***	41.61***
	(18.19)	(10.40)	(5.079)	(9.161)	(20.60)	(6.884)	(6.194)	(7.804)
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Huasman test (χ^2)	16.66	14.01	16.71	35.09**	11.48	17.98	22.82	5.59
Obs	403	403	413	403	153	157	206	152
R^2	0.397	0.00248	0.196	0.0003	0.355	0.0371	0.0878	0.192

Notes: Description of the variables can be found on Table 1. This table reports the results of the regressions based on Equation 2. High and low income sample is based on the classification of the World Bank. Robust standard errors are reported in parenthesis. Asterisks ***,**,* denote the 1%, 5%, 10% significance levels, respectively. Significant Hausman test indicates that fixed effects model is preferred, random effects otherwise.

Table 9: Low vs High income countries: Regressions on electricity production

	High income						Low income					
	(1) OILP.	(2) COALP.	(3) NUCP.	(4) REP.	(5) NATP.	(6) HYDP.	(7) OILP.	(8) COALP.	(9) NUCP.	(10) REP.	(11) NATP.	(12) HYDP.
LNGDP	-12.48**	14.28***	-2.109	-5.981***	-3.525	11.21***	12.87	-8.566**	0.273	-0.412	-47.95***	44.43***
	(6.219)	(3.137)	(1.810)	(1.387)	(6.210)	(3.440)	(8.891)	(3.519)	(0.494)	(3.430)	(8.043)	(9.593)
$LNGDP^2$	0.573	-0.978***	0.246**	0.360***	0.326	-0.646***	-0.735	0.696***	-0.0138	-0.157	2.797***	-2.645***
	(0.373)	(0.193)	(0.110)	(0.0855)	(0.376)	(0.211)	(0.630)	(0.249)	(0.0350)	(0.244)	(0.570)	(0.680)
INFL	-0.229***	-0.00591	-0.0167	-0.0161	0.125**	0.182***	-0.0254	0.0395**	0.00161	-0.00541	0.0822**	-0.0942*
	(0.0581)	(0.0285)	(0.0166)	(0.0126)	(0.0574)	(0.0315)	(0.0452)	(0.0179)	(0.00252)	(0.0174)	(0.0409)	(0.0488)
UNEMP	-0.322**	-0.0528	0.0709*	0.139***	-0.205	0.233***	1.579***	-0.00936	-0.00400	-0.238**	-0.232	-1.079***
	(0.142)	(0.0719)	(0.0415)	(0.0318)	(0.142)	(0.0790)	(0.310)	(0.126)	(0.0177)	(0.115)	(0.284)	(0.333)
RIR	-0.131***	0.0135	-0.0100	-0.0374***	0.0284	0.117***	-0.116**	0.0106	-0.00711**	-0.0124	0.0704	0.0519
	(0.0409)	(0.0199)	(0.0116)	(0.00878)	(0.0403)	(0.0220)	(0.0527)	(0.0208)	(0.00292)	(0.0204)	(0.0476)	(0.0569)
LNCO2	1.335	6.961***	-0.606	-4.176***	0.434	-7.094***	1.228	-1.817**	-0.245**	-0.483	8.255***	-8.605***
	(1.217)	(0.954)	(0.449)	(0.422)	(1.393)	(0.906)	(1.603)	(0.746)	(0.110)	(0.505)	(1.566)	(1.708)
Cons	76.54***	-103.0***	11.55	69.31***	24.78	52.57***	-45.35	54.67***	2.784	16.02	127.9***	-42.59
	(29.31)	(15.68)	(8.820)	(6.932)	(29.74)	(17.02)	(33.82)	(14.35)	(2.514)	(12.54)	(31.28)	(36.39)
Time D.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Haus. (χ^2)	29.18*	169.67***	10.67	84.26***	4.98	1.51	7.79	4.24	2.6	11.48	2.08	2.46
Obs	892	892	892	892	892	892	408	408	408	408	408	408
R^2	0.134	0.107	0.0443	0.420	0.0943	0.181	0.0971	0.105	0.0587	0.150	0.241	0.252

Notes: Description of the variables can be found on Table 1. This table reports the results of the regressions based on Equation 3. High and low income sample is based on the classification of the World Bank. Robust standard errors are reported in parenthesis. Asterisks ***,**,* denote the 1%, 5%, 10% significance levels, respectively. Significant Hausman test indicates that fixed effects model is preferred, random effects otherwise.

Appendix: Endogeneity

Table A.1: Sys-GMM: Regressions on energy consumption

	(1) ELCON	(2) FFCON	(3) RECON	(4) ANCON
Y_{t-1}	0.9926***	1.0016***	0.9901***	0.9477***
	(0.0114)	(0.0011)	(0.0041)	(0.0024)
LNGDP	0.0668***	0.2505	-0.9907***	-0.1644
	(0.0182)	(0.2471)	(0.3820)	(0.2261)
$LNGDP^2$	-0.0042***	-0.0270*	0.0635***	0.0148
	(0.0007)	(0.0146)	(0.0200)	(0.0138)
INFL	-0.0009***	-0.0115***	0.0091*	0.0035
	(0.0003)	(0.0043)	(0.0050)	(0.0024)
UNEMP	-0.0011**	-0.0187***	0.0059	0.0104**
	(0.0005)	(0.0048)	(0.0068)	(0.0050)
RIR	-0.0005***	-0.0059**	0.0030	0.0050***
	(0.0002)	(0.0025)	(0.0032)	(0.0015)
LNCO2	0.0013	0.0219	-0.0277	0.0067
	(0.0016)	(0.0166)	(0.0181)	(0.0190)
Cons	0.000	-0.1935	3.9267**	0.3989
	(0.000)	(0.9954)	(1.9069)	(0.8971)
Obs	1,228	1,239	1,666	1,224
AR(1) p-value	0.0001	0.0000	0.0030	0.0028
AR(2) p-value	0.3006	0.6908	0.7437	0.1454
Hansen p-value	0.1355	0.1598	0.1042	0.1536

Notes: Description of the variables can be found on Table 1. The table reports the results of system GMM regressions based on 4. ***, ** and * denote 1%, 5% and 10% significant level, respectively. Robust standard errors are reported in parentheses. Insignificant AR(2) indicates that second order autocorrelation does not exist. Insignificant Hansen test indicates that the GMM instruments are valid.

Table A.2: Sys-GMM: Regressions on income inequality

	(1) GINI	(2) GINI	(3) GINI	(4) GINI
$GINI_{t-1}$	0.95534***	0.98367***	0.95814***	0.97986***
	(0.01210)	(0.00491)	(0.01273)	(0.01001)
ELCON	0.18325			
	(1.44214)			
$ELCON^2$	-0.02173			
	(0.08710)			
FFCON		0.00677		
		(0.00883)		
$FFCON^2$		-0.00012		
		(0.00008)		
RECON			0.03789***	
			(0.01331)	
$RECON^2$			-0.00041***	
			(0.00016)	
ANCON				0.00422
				(0.00297)
$ANCON^2$				0.00007
				(0.00016)
INFL	-0.00053	0.00894***	0.00521	0.01178***
	(0.00796)	(0.00342)	(0.00910)	(0.00406)
UNEMP	-0.00541	0.00088	-0.00229	-0.00733
	(0.01463)	(0.00708)	(0.00997)	(0.00666)
RIR	0.01083*	0.00212	0.00431	0.00884**
	(0.00568)	(0.00244)	(0.00494)	(0.00377)
LNCO2	0.00635	0.04906***	0.04938*	0.02701
	(0.03037)	(0.01566)	(0.02984)	(0.02284)
Cons	2.65742	0.01043	0.000	0.10344
	(5.66371)	(0.18641)	(0.000)	(0.68635)
Time dummies	Yes	Yes	Yes	Yes
Obs	365	365	370	365
AR(1) p-value	0.00247	0.00360	0.00187	0.00362
AR(2) p-value	0.91014	0.91661	0.92720	0.91736
Hansen p-value	0.31976	0.58414	0.16137	0.38730

Notes: Description of the variables can be found on Table 1. The table reports the results of system GMM regressions based on 4. ***, ** and * denote 1%, 5% and 10% significant level, respectively. Robust standard errors are reported in parentheses. Insignificant AR(2) indicates that second order autocorrelation does not exist. Insignificant Hansen test indicates that the GMM instruments are valid.

Table A.3: Sys-GMM: Regressions on electricity production

	(1) OILPROD	(2) COALPROD	(3) NUCPROD	(4) RENPROD	(5) NATPROD	(6) HYDPROD
Y_{t-1}	0.9572***	0.9705***	1.0285***	1.0910***	1.0113***	0.9835***
	(0.0153)	(0.0076)	(0.0011)	(0.0047)	(0.0043)	(0.0040)
LNGDP	1.6016*	0.5323	0.2926***	-0.1916***	-0.2191	-1.2732***
	(0.8732)	(0.3221)	(0.0629)	(0.0613)	(0.5055)	(0.3585)
$LNGDP^2$	-0.0911*	-0.0334*	-0.0181***	0.0124***	0.0133	0.0772***
	(0.0509)	(0.0197)	(0.0042)	(0.0038)	(0.0293)	(0.0207)
INFL	-0.0025	-0.0025	0.0023***	0.0001	0.0003	0.0136**
	(0.0106)	(0.0048)	(0.0004)	(0.0006)	(0.0045)	(0.0059)
UNEMP	-0.0157	0.0207	-0.0009	0.0048**	0.0118	0.0318***
	(0.0186)	(0.0185)	(0.0014)	(0.0021)	(0.0080)	(0.0100)
RIR	-0.0038	-0.0030	-0.0004	0.0013**	0.0039	0.0076
	(0.0100)	(0.0045)	(0.0003)	(0.0005)	(0.0052)	(0.0048)
LNCO2	-0.1291*	0.1860***	-0.0431***	0.0153**	0.0113	-0.0407
	(0.0709)	(0.0631)	(0.0052)	(0.0074)	(0.0398)	(0.0387)
Cons	-5.1482*	-3.7335***	-0.7727***	5.7607***	0.6950	5.1977***
	(2.9155)	(1.1929)	(0.2274)	(1.3559)	(2.1001)	(1.6862)
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Obs	1,228	1,228	1,228	1,228	1,228	1,228
AR(1) p-value	0.0003	0.0002	0.0048	0.0006	0.0001	0.0012
AR(2) p-value	0.5962	0.1261	0.1263	0.8301	0.2248	0.9982
Hansen p-value	0.4072	0.4287	0.2368	0.1587	0.4949	0.1795

Notes: Description of the variables can be found on Table 1. The table reports the results of system GMM regressions based on 4. ***, ** and * denote 1%, 5% and 10% significant level, respectively. Robust standard errors are reported in parentheses. Insignificant AR(2) indicates that second order autocorrelation does not exist. Insignificant Hansen test indicates that the GMM instruments are valid.