Revisiting Environmental Kuznets Curves Through the Energy Price Lens.

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Research Highlights

(1) EKC literature usually dismiss the major influence of energy prices.

(2) Relative energy prices invalidate the evidence in favor of the EKC hypothesis.

(3) Results may explain some contradictory observations found in the EKC literature.

(4) Nowadays reduction in energy prices may break decarbonization trends.

(5) Direct action by policymakers is required to break the positive GDP-CO$_2$ link.
Abstract

The goal of this paper is to provide new insights to elucidate the inconclusive results from the Environmental Kuznets Curve (EKC) empirical literature. For the first time in empirical literature, an econometric analysis includes the relative prices for several energy sources. The paper provides strong evidence on the relevance of energy prices to CO₂ emissions. Accordingly, one reason for the lack of agreement in the EKC literature may be the absence of energy prices in empirical exercises. The presence of relative energy price changes in the econometric specification confirms a monotonic and positive relationship between CO₂ and gross domestic product (GDP). Therefore, we may conclude that there is a decoupling process but without reaching any turning point on that relationship. The policy implications are straightforward. Direct climate action by policy makers is required to break the positive relationship between CO₂ and GDP. That conclusion has been reinforced by the reduction of energy prices since the middle of 2014. Otherwise, the trend in energy prices may reverse the relative decarbonisation processes accounted for in recent years in major developed countries.
1. Introduction

An important strand of literature searches for relationships between CO$_2$ emissions and gross domestic product (GDP), population growth, or both variables simultaneously. The underlying idea behind most papers in the literature is the Environmental Kuznets Curve (EKC) hypothesis: a sort of inverted U-shaped curve that relates pollution to economic development. It suggests that per capita CO$_2$ emissions may rise as a response to per capita income growth in the early stages of economic development up to a turning point, after which emissions begin to decline.

The EKC hypothesis seems to beg the question of whether income growth beyond a turning point might serve as a solution to environmental degradation, rather than representing the source of the problem (Kaika and Zervas, 2013a, includes a very interesting literature review on this issue). Thus, the search for a turning point is central in the EKC literature as highlighted, for instance, in Galeotti and Lanza (1999). Their survey includes some references in favour of the EKC hypothesis but the estimated turning points are beyond the sample income levels (e.g., Holtz-Eakin and Selden, 1995; Cole et al., 1997). Strictly speaking, these papers only provide evidence of a decreasing marginal propensity to emit greenhouse gases. There are also papers that estimate turning points within sample income levels. Some recent examples are provided in the work of Ang (2007), Coondoo and Dinda (2008), Apergis and Payne (2009), Dutt (2009), and Pao and Tsai (2010).

An important policy implication derives from those papers providing evidence in favour of the EKC for CO$_2$ with turning points within sample income levels; further increases of incomes beyond the turning points lead to unambiguous reductions in CO$_2$ emissions.
Consequently, favourable evidence in the EKC literature might legitimize lax political responses to climate change (or delays in adopting environmental policies [e.g., Beckerman, 1992]), as long as it provides a medium- and long-term solutions. That kind of statement is explicit or implicit in some papers’ messages. In some cases, authors seem to agree with this view; others just mention that it may be the conclusion behind any eventual support of the EKC hypothesis and/or within-sample turning points (for recent examples, see, for instance, Richmond and Kaufmann 2006b; Apergis and Payne, 2009; Pao and Tsai, 2010; and Niu et al., 2011). Dutt (2009) makes an important point with regard to the view that the EKC hypothesis can legitimize lax political responses: “Based on all the findings so far, this [increase in income automatically resulting in lower emissions] does not seem to be the case. […] Policies, combined with better institutions and public awareness could have helped reduce emissions, and in this study these happen to be associated with high-income countries”.

Many papers have questioned whether the empirical data accommodates the EKC hypothesis. The main insight from the empirical literature is highlighted by Kaika and Zervas (2013a) as follows: “the EKC literature is quite large, and results are at best mixed. No clear conclusion can be drawn”. As Agras and Chapman (1999) point out, the EKC hypothesis arises from a set of relationships that need to be fully identified. One important relationship that might influence the EKC hypothesis is the interaction between pollution and energy prices. However, energy prices have been omitted from most of the empirical specifications.

The main objective of this particular research is to provide additional evidence of the important role of energy prices in the EKC debate. Our main hypothesis is that
substitution and income effects in response to energy price changes exert a major influence on the relationship between GDP and CO₂ emissions.

This paper contributes to the literature by including, for the first time in an empirical EKC model, relative energy prices (for coal, oil products and natural gas). The focus of this paper is on OECD countries because they are more likely than other countries to display the turning point predicted by the EKC hypothesis. Our results emphasise the need to account for relative energy prices in order to avoid biased conclusions. The paper develops in the following manner: Section 2 reviews the literature on the EKC hypothesis; Section 3 presents the econometric methodology; Section 4 introduces the data employed in this study; Section 5 provides the econometric results and some further discussion; finally, Section 6 summarises the paper’s conclusions and its main policy implications.

2. A survey of the literature

The literature on the EKC hypothesis began, to our knowledge, with the research agenda developed by the World Bank as part of the World Development Report (see, for instance, the series of working papers published in 1992: Lucas et al., 1992; Radetzki, 1992; Shafik and Bandyopadhyay, 1992). As a result of this line of research, Beckerman (1992) concludes that the “strong correlation between incomes and the extent to which environmental protection measures are adopted demonstrates that, in the longer run, the surest way to improve your environment is to become rich”.

The main pillars of the theoretical explanations in the EKC hypothesis are the income effect, the structural effect and the abatement effect (see, for instance, recent surveys in
Kijima et al., 2010; Jaunky, 2011; and Kaika and Zervas, 2013a). We may summarise the main insights from this hypothesis as follows. Usually, economic development results from structural changes experienced by national economies, from primary to industrial and, later on, service–knowledge-based economies. Those structural changes generate a national pollution transition in such a way that countries develop a path of increasing per capita CO₂ emissions during the first stages of economic development. Later on, they transition towards using less energy, and lower natural resource consumption rates and eventually reduce per capita CO₂ emissions. In addition, economic development (summarized as a greater income per capita) generates an income effect that increases the consumption of goods and services and, therefore, per capita CO₂ emissions. Finally, the abatement effect takes place when economies achieve the greatest economic development. At that point, they will be able to invest more resources (both private and public) in environmental protection and efficient technologies that eventually reduce per capita CO₂ emissions (thanks to increasing awareness of environmental problems that will impact consuming and voting behaviours). Thus, the main hypothesis in the empirical literature is that the combination of these three effects may result in an inverted U-shaped curve explaining the CO₂-to-GDP relationship.

Despite the growing number of analyses providing support for the EKC hypothesis, some literature surveys have questioned the validity of this hypothesis because of inconclusive results, as many papers failed to provide such positive support. According to several authors, some analyses may suffer from technical weaknesses and bias due to omitted variables (for expositions on these issues, see, for instance, the surveys in Stern, 1998 and 2004; Dinda, 2004; He, 2007; and Kaika and Zervas, 2013a and 2013b).
Consequently, Borghesi and Vercelli (2003) and Stern (2004) conclude that the EKC hypothesis might not be generally acceptable for use in the case of carbon emissions, although it may be correct for those studies based on local emissions.

Following this line of research, some recent papers stress the need for more robust statistical inferences on the EKC hypothesis. According to some authors, such as Vollebergh et al. (2009) or Musolesi and Mazzanti (2014), the controversy around using EKC to predict CO$_2$ may be related to the identification dilemma that researchers faced. They conclude that the EKC evidence is explained to a large extent by country-specific, time-related factors. In particular, Musolesi and Mazzanti (2014) find that out of a panel of 20 OECD countries, “only three Scandinavian countries – Denmark, Finland and Sweden – present some threshold effect on the CO$_2$-development relation, whereas for all other countries this relation appears to be monotonic and positive”. Unsurprisingly, Finland and Sweden present a very particular electricity-generation mix (as most of these countries’ energy is generated by hydroelectric and nuclear power plants). Besides, these countries benefit from participation in the integrated Nordic power market (known as Nord Pool, which also includes Denmark and Norway), thus further expanding hydroelectric generation capacity. Unfortunately, that particular mix of generation options is not accessible to all countries because of the unavailability of natural resources and political restrictions.

Following the line of reasoning highlighted in the previous paragraph, energy prices may be regarded as useful variables for improving the identification of robustness by disentangling the effect of GDP on CO$_2$ emissions from unobserved time-related effects. Agras and Chapman (1999) make the first attempt at including energy prices as an explanatory variable to study EKC for CO$_2$ emissions; the same variable is used for
all countries in the sample (real gasoline prices in the United States). Richmond and Kaufmann (2006a), however, use country-specific, end-user prices (the price of light fuel oil for industry) to take into account the differences in tax burdens and any other structural constraints that affect the final prices. They find evidence in favour of the EKC-type relationship, but it vanishes when the energy price is included. Additionally, the coefficients associated with GDP are not significantly different from zero when energy prices are included. Finally, Burnett et al. (2013) include a set of energy prices (in a way that is very similar to our approach for studying energy-related CO$_2$ emissions) at the state level in the United States.

The empirical literature has also tested the impact of elements aside from energy prices—see for instance the latest studies in the *Energy Policy* journal on this issue: Saboori and Sulaiman (2013), Song et al. (2013), Kanjilal and Ghosh (2013), Ozcan (2013), Farhani et al. (2014), Lau et al. (2014), Robalino-López et al. (2014), Al-Mulali et al. (2015), Yin et al. (2015). These additional elements are beyond the scope of this paper.

As mentioned, the controversy surrounding the empirical evidence against and in favour of the EKC hypothesis deserves further research. Accordingly, we contribute to the empirical literature by including relative energy prices for the first time.

3. **Methodology**

In this section, we outline the econometric methodology that we use to validate the EKC hypothesis for CO$_2$ emissions. As previously mentioned, there is not a consensus in the
empirical literature on the relationship between economic growth and CO2 emissions. This absence of consensus may be related to the identification dilemma researchers faced when looking for a proper reduced form of estimation for the inverted U-shaped curves, as long as “it is crucial to proper inference to impose identifying assumptions that separate the effect of the independent variable from the unobserved effects” (Vollebergh et al., 2009). Panel-data analysis should improve identification problems by allowing for controls to capture unobserved fixed effects at the country level. Nevertheless, these authors sustain that some identification problems remain as long as pollution and income are both time-related through different unobserved channels, such as, for instance, tendencies in technological developments. The lack of proper identifying assumptions may yield biased and non-robust estimates.

The purpose in this paper is to use end-user energy prices (in relative terms) to disentangle the effect of GDP on CO2 emissions from unobserved time-related effects. On the one hand, an increase in relative prices may produce substitution effects (e.g., among different energy sources, between energy and other final goods, and between energy and other intermediate inputs or primary factors). On the other hand, it may boost investments in energy efficiency (e.g., by households, by firms for their production processes, and by firms for the energy efficiency incorporated into the final goods that they produce). Additionally, an increase in energy prices may reduce energy consumption and CO2 emissions because of a reduction in real income.

Following the same reasoning, Musolesi and Mazzanti (2014) acknowledge that, apart from bias due to omitted time-related factors, EKC estimates may also suffer from functional-form and heterogeneity biases. They conclude that, for a panel of 20
developed countries, the EKC evidence is explained to a large extent by country-
specific, time-related factors (the same kind of results found in Vollebergh et al., 2009).
On this ground, we base our analysis on Musolesi and Mazzanti (2014) and additionally
account for energy prices and energy independence. Thus, we estimate a fixed-effect
panel data model with homogeneous income effects, individual fixed effects, and
individual time effects, as follows:

\[ d_{it} = \beta_1 y_{it} + \beta_2 y_{it}^2 + \beta_3 P_{it} + \beta_4 X_{it} + g_i(t) + u_{it} \]

Where \( i = 1, \ldots, N \) and \( t = 1, \ldots, T \). We will assume that the fixed effect \( u_{it} \) follows a one-way
error-component model:

\[ u_{it} = \mu_i + \nu_{it} \]

where \( \mu_i \sim \text{iid} \left(0, \sigma_\mu^2\right) \) and \( \nu_{it} \sim \text{iid} \left(0, \sigma_\nu^2\right) \) are independent (both of each other and
among themselves).

In this model, \( d_{it} \) is the per capita CO\(_2\) discharged into the environment, \( y_{it} \) is the per
capita GDP at purchasing power parity, \( P_{it} \) is the set of energy prices, \( X_{it} \) is the set of
variables accounting for the national endowment of energy resources, and \( g_i(t) \)
represents country-specific time trends (the next section and Appendix A provide a
detailed explanation of the variables).

The individual or country fixed effects (\( \mu_i \)) are those idiosyncratic elements that are
invariable in our time-frame analysis. This may include not only permanent conditions
(e.g., institutions, culture, and geographic or climatic conditions) but also population
distribution (e.g., urban sprawl; see Bataille et al., 2007, for further discussion). These
features may be better understood as somewhat inflexible national characteristics in our analysis (26 years); therefore, it is improbable that they can be dramatically modified by policy pressures or shocks in the short term. We have tested for the convenience of fixed-effects estimation in our panel of countries using the Hausman test, and fixed effects appear to be preferable to random effects. Moreover, we have tested our data for cross-sectional independence and the presence of unit roots. More details on all these statistical tests may be found in Appendix B.

We also attempt to control for country-specific characteristics which are time-variable by including energy-independence share: the share of total primary energy supply that is domestically produced (with both domestic and international destinations) for each source. Energy-independence shares allow us to account for structural energy constraints such as shortages and excesses of domestic endowments with regard to energy consumption. Consequently, these shares might, to some extent, capture the nation’s level of energy independence and, therefore, its energy security.

However, the usual approach in the empirical literature is to include energy shares (out of primary consumption) instead of energy-independence variables (see, for instance, Marrero, 2010). The inclusion of energy shares (e.g., the energy mix) may be subject to criticism from a methodological point of view. Certainly, that sort of fuel-mix regression model might maximise the goodness of fit to the data. However, such a result may be the consequence of an accounting identity, which might bias the specification. Usually, energy agencies and national statistical services estimate carbon emissions as a weighted sum of fuel consumption multiplied by fixed coefficients that reflect the carbon content of each type of energy. As a result, changes in energy shares may explain changes in CO₂; therefore, little explanatory room is left for GDP. Thus, the
inclusion of those variables in the empirical exercise will jeopardise the explanation of GDP’s impact on carbon emissions.

Our empirical model also includes country-specific time trends, \( g_i(t) \), which capture unobservable time-related factors that may heterogeneously affect different countries. These individual time effects may include elements such as trends (individual transitional changes) in technology, economic structure, and so on. Finally, our empirical model includes some other time-related factors that may homogeneously affect all countries, such as global economic shocks and policy developments (e.g., international agreements on trade and the environment), which are accounted for by year dummies.

We perform different specifications to assess the robustness of our results. First, we estimate a basic EKC equation that includes the energy-independence shares and the price for refined oil products but not year dummies and time trend variables. This specification allows us to compare our results with one of the few studies that includes energy prices (Richmond and Kaufman, 2006a). Furthermore, it provides a reference point for comparison with alternative specifications once we include additional variables such as supplementary energy prices, year dummies (two-way error model) and country-specific time-trend variables. For the latter, we assume that the individual time trend effects are linear, but that might be a questionable postulate. To check the robustness of our results from the parametric specification, we further relax that assumption by using non-parametric, country-specific time effects, following suggestions from some recent papers (e.g., Musolesi and Mazzanti, 2014).
Summing up, the approach followed in this piece of research is aggregation with country-based insights, including: (i) individual fixed effects to capture any idiosyncratic elements that are invariable in our time frame analysis; (ii) individual time trends to capture any unobservable time-related factors heterogeneously affecting different countries; (iii) national end-user energy prices (in relative terms) to improve identification robustness; and (iv) the share of total primary energy supply that is domestic, thus capturing to some extent the nation’s level of energy independence and, therefore, its energy security.

4. Data

The focus of this paper is on 15 OECD countries: Austria, Belgium, the Czech Republic, Denmark, Finland, France, Hungary, Italy, Japan, Poland, the Slovak Republic, Switzerland, Turkey, the United Kingdom and the United States. According to the EKC hypothesis, these countries may be rich enough (per GDPpc) to be on the right side of the inverted-U relationship (for a similar approach, see the in-depth survey in Kaika and Zervas, 2013a and 2013b). The lack of data for other OECD countries (mainly energy prices, which are a key element in this research) restrict our sample to an almost\(^1\) balanced panel of countries and to the period of 1979 to 2004 (similar constraints are reported in Richmond and Kaufmann, 2006a & 2006b). These data are available in the databases “Energy Statistics of OECD countries, 2007 edition” and the “Energy Prices & Taxes 2nd Quarter 2007” published by the International Energy

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\(^1\) We lack the first three observations for the price of natural gas in Turkey. This is not a problem as long as the effect of natural gas is not significant for our preferred specification.
Agency and OECD (Appendix A provides further details about the variables). We have excluded previous years to avoid the known structural changes that occurred in the 1970s in response to important oil-market disruptions, such as the Organization of the Petroleum Exporting Countries (OPEC) oil embargo in 1973 and the Iranian Revolution in 1979. Moreover, the lack of data for some of the energy prices (mainly carbon and gas) in the time before the 1980s restricts the sample considerably. Similarly, we have excluded recent years to avoid the effects of economic shocks related to the financial crisis. Both oil-price and financial shocks may introduce structural breaks in the time series, thus causing changes in means or in the other parameters of the process that produces the series. These represent additional statistical problems that must be correctly handled to disentangle the impact of GDP on CO₂ emissions from the effects of other variables. We try to avoid these sorts of problems to provide more robust statistical results.

As mentioned in the previous section, we contribute to the empirical literature by being the first researchers to include relative energy prices. These data may convey some unobserved time-related effects of CO₂, either homogeneously in all countries (e.g., international energy-market developments) or idiosyncratically (e.g., fiscal and market regulations that eventually impact end-user energy prices). Very few papers have included energy prices to explain the EKC hypothesis (see, for instance, the last survey published by Kaika and Zervas, 2013a). This may be due to the lack of data available for some energy sources (e.g., coal), even in OECD countries. As a result, some authors use oil prices as a proxy for all energy prices. However, any researcher who uses this specification will be unable to take into account the substitution effects driven by relative price changes. Accordingly, the relative prices of coal and gas with respect to
refined oil products have been included in our empirical model as additional explanatory variables.

We have excluded electricity prices from the empirical model for two main reasons. First, it is a tradition in developed countries that electricity prices have been highly regulated, with minor inter-year variations. These prices thus have a low explanatory value for any empirical purpose, which probably explains the non-significance of electricity prices in Richmond and Kaufmann (2006b). Second, other energies, such as coal, oil and natural gas, may act as fuels for the production of electricity, thus causing a sort of double-accounting channel for those prices; this should be avoided.

Accordingly, we manage to include both a 20-year decline in oil prices and the increase in those prices during the 2000s. During that period, nominal oil prices completed a full reversal, returning to a price of approximately US$40 in 2004 after last being at that level in 1980, and reaching a bottom of US$12 in both 1986 and 1999 in the interim. In real terms, our database includes an important decrease in oil prices for the whole period. That variability in energy prices (as illustrated here in the case of oil) should reduce identification problems, thus providing a more robust model. Furthermore, the OECD countries included are at different stages, in terms of both their development process and their per capita CO₂ levels; the study includes European Union countries, former Soviet Federation republics, the United States and Turkey). Table 1 summarises the main descriptive statistics. For the empirical exercise presented in the next section, all data are presented in logarithmic form.

[ insert Table 1 here ]
5. Results and discussion

This section presents the results, and it will highlight the important role of energy prices to disentangle the effect of GDP on CO$_2$ emissions from unobserved time-related effects.

5.1 Results

We first estimate a basic EKC equation, including the share of total primary energy supply that is produced domestically and the price for refined oil products but not the time variable. This is close to the specification provided in Richmond and Kaufmann (2006a), which is shown in the first column of Table 2. Keep in mind that we use, first the weighted average of industry and household refined-oil products (instead of industrial light-fuel oil, as in Richmond and Kaufmann, 2006a), and, second, proxies for national energy independence (rather than the energy mix, as used in Richmond and Kaufmann, 2006a).

[ insert Table 2 here ]

The results from the first column in Table 2 reveal a positive and significant effect of GDP$_{pc}$ and a negative effect of refined oil prices on carbon emissions. Actually, our results for GDP$_{pc}$ and oil prices are very close to the estimates in Richmond and Kaufmann (2006a). Additionally, we find a non-significant coefficient for the coal independence share and significant coefficients for oil and natural gas independence shares (which have negative and positive signs, respectively). The fact that CO$_2$ emissions may not respond to changes in the independence share of coal suggests that the independence shares might be capturing unobservable, idiosyncratic features; therefore, we should not attempt to draw a conclusion from their coefficients. The
negative sign for the oil independence share reinforces that view. We should keep in
mind that the purpose of energy-independence variables is to discard biased results from
the relevant omitted variables. In other words, we are much less interested in the
coefficients that are linked to energy-independence variables than in the robustness of
the empirical evidence with regard to the EKC hypothesis and the role played by energy
prices.

We could make some comments regarding the carbon-free energy-independence share.
This figure measures the share of total primary energy supply due to renewable and
nuclear energy. We could assume that countries usually display a narrow capacity to
import/export carbon-free energy (apart from biomass sources, which are marginal in
our panel of data). Therefore, our results suggest that an increase in carbon-free energy-
independence shares contributes to a reduction in national carbon emissions.

As mentioned in different sections in this paper, it is important to account for the prices
of different energy sources. As a result, the second column in Table 2 includes several
energy prices (refined oil, coal and natural gas), all of which had significant
coefficients. Surprisingly, regarding the results from the previous paragraph, this
provides evidence in favour of the EKC hypothesis and the existence of a turning point
(the second column in Table 2 displays a highly significant coefficient for the square of
GDP). These results are in line with those provided in Burnet et al. (2013). This is also
the case when no energy price is included in the econometric specification (although
this result was omitted in the text due to a lack of interest). However, Table 2 offers a
counter-intuitive result which suggests that a rise in the price of oil products may
increase CO₂ emissions (as the coefficient signs for energy prices are the same as those
reported in Burnet et al., 2013), which contradicts the evidence from the first column.
Perhaps the reason for this unexpected result is that a rise in oil prices will increase coal consumption, and the latter is far more polluting.

We wonder whether these changes in coefficients for oil prices and the square of GDP (as shown in Table 2) reflect the model’s inability to accurately account for price elasticities and substitution effects among energy sources. That is indeed the main motivation for including relative energy prices. The third column in Table 2 corroborates this intuition. In particular, an increase in the price of coal relative to that of oil would decrease per capita CO$_2$ emissions. Our results provide an additional finding: we are no longer able to provide evidence in favour of the EKC hypothesis because the squared GDP term becomes non-significant once relative prices are included in the model.

To check the robustness of that evidence, we proceed to the last two columns in Table 2, which include year dummies and country trends. Interestingly, the main conclusions obtained from the third column in Table 2 remain unchanged: (i) relative energy prices are significant variables in explaining CO$_2$ emissions, (ii) they are responsible for the model’s inability to provide evidence in favour of the EKC hypothesis, (iii) there is almost no significant change in the coefficients, and (iv) there is a positive relationship between GDP and CO$_2$ emissions. The elasticity of CO$_2$ emissions relative to GDP is smaller than 1 (approximately 0.5, to be more precise). Finally, we obtain a non-significant coefficient for the price of natural gas relative to that of oil, as expected according to their similar carbon contents.

A detailed study of the residuals of the preferred model (Column 5 in Table 2) shows a correct fit. When we compare the observed values with the values predicted by the
model for each individual country, we conclude that our model achieves a very good fit for all individual behaviours (see Figure 1). Appendix B provides further information on the goodness of fit and the residual analysis of the model.

[ insert Figure 1 here ]

5.2 Robustness of the model

As mentioned in the Methodology section, following the suggestions from some recent papers, like Musolesi and Mazzanti (2014), we have also checked the robustness of our linear model by allowing for non-linear effects of time relative to the response variable. More precisely, we have compared the linear specification with a partially linear model (see, for example, Härdle et al., 2004, for a general reference regarding partially linear models). With that purpose, we have worked with the regression model given in Section 3, in which the function $g_i(t)$ is non-parametric. Block (a) of Table 3 shows the results for a simplified version of the model with no country-specific or year-specific effects and a common non-parametric trend—that is, $g_i(t)=g(t)$ for all $i$. In this case, there is a total agreement between the linear model and the partially linear model in terms of the magnitudes of the coefficients and their significance. However, when non-parametric, country-specific time trends are included in the partially linear model (Table 3, Block b), changes in the magnitude and significance of some coefficients appear relative to the linear model (5) in Table 2. It is important to notice that the inclusion of country-specific trends enormously complicates the estimation procedure for the partially linear model; we have observed that non-stable estimators are produced. In particular, the
coefficient associated with the GDP is too large to be credible, as it would imply an explosive increase in emissions. In our opinion, the fact that only 26 observations are available for each country results in poor non-parametric estimators. To summarize, taking into account both that the simplified models show a general agreement between the linear and the partially linear models and that the relative energy prices available constrain the number of observations for each country, we believe that the linear approach is more suitable for the data analysed in this research. Consequently, as long as we exploit the unobserved information contained in energy prices and energy-independence indicators, we can conclude that (in this particular case) the gain from using complex non-parametric estimation techniques is limited and that such a method is inadvisable.

[ insert Table 3 here ]

5.3 Discussion

Now we may proceed with the main insights from this piece of research. We have provided empirical evidence of a positive relationship between GDP and CO$_2$ emissions. This conclusion is robust to the inclusion of year dummies and country-specific trends that control for unexpected shocks (which are common for all countries), technological developments (e.g., differences in the time frame for the adoption of new technologies), and national circumstances (e.g., nuclear power development, natural resource availability, geography and climate) captured by fixed effects and energy-independence variables. As expected, a greater share of total primary energy supply devoted to carbon-free energy contributes to a reduction in national carbon emissions and a rise in national energy independence (and therefore energy security) by reducing the consumption and import (respectively) of fossil fuels.
The elasticity of CO$_2$ emissions relative to GDP is around 0.5. Therefore, there is indeed a decoupling process between these variables. Nevertheless, there is no evidence of an eventual turning point, and we only find a relative decoupling. Therefore, once a high-enough GDP level is reached, we should not expect a reversal in the relationship between GDP and CO$_2$ emissions. Thus, GDP generates an important (but marginally decreasing) positive influence on the path of CO$_2$ emissions.

As expected, the relative energy prices exert a significant influence on CO$_2$ emission volumes associated with GDP levels. We may illustrate this channel through relative energy prices’ impact on the EKC (Figure 2). This figure shows a hypothetical representation of a positive and monotonic GDP-CO$_2$ relationship for a particular country, both before (blue line) and after (red line) a significant rise in energy prices. Therefore, the increase in energy price, ceteris paribus, will shift the EKC downwards by decreasing energy consumption and CO$_2$ emissions for any level of GDP. Let us assume that the price increase takes places simultaneously with a sustained rise in GDP. The conjunction of these two trends can be represented by the black line in Figure 2. Thus, an empirical assessment of the data generated by this graphical representation (black line) might provide evidence in favour of the EKC, despite the fact that each single-coloured line represents the true relationship between GDP and CO2 emissions.

[ insert Figure 2 here ]

The graphical analysis provided by Figure 2 emphasises the results from our empirical exercise: any research which fails to include energy prices may be jeopardising the robustness of its empirical results in favour of the EKC hypothesis. This result may explain why “the EKC literature is quite large, and results are at best mixed” (Kaika and
Accordingly, relative energy prices provide valuable information for disentangling the effect of GDP on CO\textsubscript{2} emissions from unobserved time-related effects, thus reducing identification problems.

From a political point of view, our results highlight that direct climate change policy is required to break the positive relationship between CO\textsubscript{2} and GDP (e.g., technological standards of energy efficiency and emissions, carbon pricing and support for renewables). The call for climate action is further stressed by the current decline in energy prices (particularly, the steep fall in oil prices since mid-2014). That trend may reverse the decarbonisation processes of recent years in major developed countries. Lower energy prices encourage greater consumption of fossil fuels and emissions, and they dissuade investments in energy efficiency and renewable resources from both firms and households, thus shifting the EKC upwards.

Our evidence on the relevance of relative energy prices is linked to the adoption of policies that eventually impact energy prices (e.g., green taxes, emission rights and support polices for renewables), but there are of course many other policies available for climate change action, as we have mentioned before. Some revenue-increasing policies such as green tax reforms, based on the double-dividend hypothesis devised by Pearce (1991), may produce additional benefits such as more efficient tax systems or lower public deficits. Furthermore, environmental taxes might play an important role in easing political constraints regarding the reform of public budgets in countries experiencing fiscal stress (Gimenez and Rodriguez, 2016).

Following this line of reasoning, the current drop in energy prices (e.g., oil prices’ fall from above US$100/b in early 2014 to around $40/b two years later) may represent a
sort of low-price window for those policy makers who are willing to implement new political initiatives (erasing undesirable subsidies, increasing taxes for some products and sectors, etc.).

6. Conclusions and policy implications

This piece of research provides important evidence on the role of final energy prices in the EKC debate. In particular, the inclusion of changes in relative energy prices invalidates the evidence that we might otherwise find in favour of the EKC hypothesis in our econometric exercise. Our focus on final energy prices relates to the fact that they may provide valuable information related to unobserved, country-specific time factors. We may conclude then that the widespread omission of relative energy prices may explain the apparent contradiction of the results published in the empirical literature: significant empirical evidence both in favour of and against the EKC hypothesis. Thus, results from this paper emphasise the need to account for relative energy prices to avoid biased conclusions.

Accordingly, we can conclude that there is a positive (but marginally decreasing) relationship between GDP and CO₂ emissions (the elasticity of CO₂ emissions relative to GDP is around 0.5). We only find a relative decoupling between both variables. Consequently, we should expect more stress episodes on environmental grounds in the near future due to the instability in energy markets that has existed since 2014, pushing energy prices downward and national emissions upward for any level of GDP.

Direct climate action by policy makers is required to break the positive relationship between CO₂ and GDP. This could be implemented through several means, including
direct regulations (e.g., technological standards for energy efficiency and emissions) and policy instruments based on the market (e.g., carbon pricing and support for renewables). Actually, the latter kind of instrument may be preferred in a situation with low energy prices as long as policy makers can take advantage of that scenario to implement new climate-change initiatives (e.g., erasing undesirable subsidies or increasing taxes for some products and sectors).

References


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Richmond, A., Kaufmann, R., 2006b. Is there a turning point in the relationship between income and energy use and/or carbon emissions? Ecological Economics 56, 176-189.


Romero-Avila, D. 2008. Questioning the empirical basis of the environmental Kuznets curve for CO2: new evidence from a panel stationarity test robust to multiple breaks and cross-dependence. Ecological Economics 64, 559-574.


Appendix

Appendix A: Variable definitions

$CO_2$ discharge on the environment: $CO_2$ sectoral approach (mt of $CO_2$).

$Gross$ $domestic$ $Product$ $per$ $capita$: US$2000$ using PPPs per person (expressed in thousands).

$Total$ $primary$ $energy$ $consumption$: it includes oil, coal, gas and renewable (ktoe per person).

$Weighted$ $average$ $price$ $of$ $oil$ $products$: US$2000$ using PPPs/kl. It is calculated as a weighted average of industry and household prices (we use the final consumption as weights). Industry prices include representative heavy fuel oil, light fuel oil and automotive diesel, but not fuels used for electricity generation. The household index includes representative gasoline and light fuel oil.
Weighted average price of coal: US$2000 using PPPs/ton. It is calculated as a weighted average of industry and household prices (we use the final consumption as weights). For coal, the industry index includes representative steam coal and coking coal. The household index includes steam coal.

Weighted average price of gas: US$2000 using PPPs/m$^3$. It is calculated as a weighted average of industry and household prices (we use the final consumption as weights).

Oil, coal, gas or carbon free energy independence: domestic production for each energy source before including imports and exports relative to total primary energy (ktoe).

Carbon free resources includes renewables and nuclear energy

Appendix B: econometric issues

Testing fixed-effects

Within this class of models, the fixed-effects specification is a common choice for macroeconomic analysis, and it is believed to be more appropriate than a random-effects model for two reasons. First, if the individual effect represents omitted variables, it is likely that the country-specific characteristics are correlated with the other regressors. Second, a typical macro panel is not likely to be a random sample from a larger universe of countries. Moreover, we have tested for fixed effects by using the Hausman test in all specifications; fixed effects are preferable to random effects.

Testing unit roots
The presence of unit roots may lead to specification bias. Accordingly, we test to
determine if the dependent variable contains unit roots as long as our panel-data
analysis relies on stationary data. To implement the right unit-root test for our panel, we
have to take into account its size—in this case, 15 unit panels (N) and 26 time periods
(T). For this type of panel (a small number of individuals and a small or moderate
number of time periods), it is typically assumed that N is fixed and that T tends to
infinity. A test in which N approaches infinity as the time dimension approaches infinity
could also be used, although such tests work best with large values of T and at least a
moderately sized N.

Three tests might be applicable to our sample. The first is the LLC test (Levin, Lin and
Chu test: Levin, et al., 2002), which is recommended for panels of moderate size (i.e.,
between 10 and 250 panels and 25 to 250 time periods per panel). Additionally, the
requirement that N/T approaches 0 implies that N should be small relative to T (Baltagi,
2008). The second is the IPS test (Im, Pesaran and Shin test: Im et al., 2003), which is
appropriate when both N and T are fixed. Im et al. calculated exact critical values using
simulations. Finally, Choi’s (2001) Fisher-type test, for which both the inverse-normal
and inverse-logit transformation can be used, is appropriate when N is finite or
approaching infinite. Simulation results suggest that the inverse-normal statistic offers
the best trade-off between size and power.\(^2\) The null hypothesis for these tests is that

\(^2\) Maddala and Wu (1999) and Maddala et al. (2000) find that the Fisher-type test is superior to the IPS
test, which in turn is more powerful than the LLC test. Choi (2001) shows that the empirical sizes of the
IPS and Fisher tests are reasonably close to their nominal sizes of 0.05 when N is small, but the IPS test
has the most stable size. In terms of the size-adjusted power, the Fisher-type test seems to be superior to
the IPS test.
each series in the panel contains a unit root, and the alternative hypothesis allows for some (but not all) of the individual series to have unit roots (i.e., these tests are designed to reject the null hypothesis only when the evidence against it is sufficiently overwhelming). Alternatively, tests by Hadri (2000) and Hadri and Larson (2005) reverse the roles and considered the null hypothesis of stationarity against the alternative of a unit root. However, these tests are designed for cases with large T and moderately sized N. Hlouskova and Wagner (2006) performed a large-scale Monte Carlo simulation to study the size and power of the panel-unit root and stationarity test, finding that the panel stationarity test of Hadri (2000) and Hadri and Larsson (2005) perform poorly.

Recent literature has shown that structural changes which shift the mean and/or the trend of the individual time series could bias the results of the unit-root test (see Carrion-i-Silvestre et al., 2005, or Bai and Carrion-i-Silvestre, 2009). In our case, we have restricted the sample to a period without important (known) structural breaks to minimize their possible effects. Moreover, to implement this test, our sample should be larger (large T and moderately sized N). Romero-Avila (2008) tested both per capita GDP and per capita CO$_2$ in a larger sample and found that both variables exhibit a trend of broken stationarity for European countries.

As a result, we have implemented LLC, IPS and inverse-normal Fisher-type tests, allowing for the incorporation of trends and showing good finite-sample properties (see Table A1). When the trend is included, the null hypothesis (“all panels contain unit

3 See Romero-Avila (2008) for a detailed analysis of unit roots, including structural breaks for both per capita GDP and per capita CO$_2$. 


roots”) is rejected for both per capita CO₂ and per capita GDP in all tests except the IPS test for per capita GDP.

[ insert Table A1 here ]

Testing for cross-sectional independence

Cross-sectional dependence may lead to lost efficiency in estimates. Accordingly, we have performed a bias-corrected LM test based on the paper by Baltagi et al. (2012), who developed a scaled version of the LM test in the context of a fixed-effects, homogeneous panel-data model. Results for each specification of the model are reported in Table 2. The null hypothesis of cross-sectional independence is rejected for the first three specifications (i.e., before including the time effects). Once the time dummies and/or the country-specific trends are included in the model, there is no evidence of cross-sectional dependence in the results.

Goodness of fit and residual analysis

A detailed study of the residuals from the preferred model (Column 5 in Table 2) shows a correct fit. First, the residuals do not show a deviation from normality (see the left panel in Figure A1). Apart from very few possible outliers, the normal QQ-plot reveals a good fit for normality. In fact, after just removing the most extreme outlier (1 residual out of 387), the p-values of the Jarque-Bera and Shapiro-Wilk tests for normality are 0.156 and 0.179, respectively. Furthermore, there is no evidence of any clusters of
countries in terms of fitting qualities that differ from those of the whole sample (see the right panel in Figure A1).

[ insert Figure A1 here ]
Table 1: Descriptive statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Obs</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ pc</td>
<td>387</td>
<td>9.32</td>
<td>3.94</td>
<td>1.66</td>
<td>21.66</td>
</tr>
<tr>
<td>GDP pc (using ppp)</td>
<td>387</td>
<td>19.13</td>
<td>7.43</td>
<td>4.53</td>
<td>36.24</td>
</tr>
<tr>
<td>Oil prices ($/kl using ppp)</td>
<td>387</td>
<td>933.66</td>
<td>412.36</td>
<td>292.76</td>
<td>2465.90</td>
</tr>
<tr>
<td>Coal prices ($/t using ppp)</td>
<td>387</td>
<td>150.92</td>
<td>126.96</td>
<td>25.31</td>
<td>624.41</td>
</tr>
<tr>
<td>Gas prices ($/m³ using ppp)</td>
<td>387</td>
<td>431.63</td>
<td>196.59</td>
<td>89.44</td>
<td>1147.46</td>
</tr>
<tr>
<td>Coal prices/oil prices</td>
<td>387</td>
<td>0.19</td>
<td>0.19</td>
<td>0.02</td>
<td>0.89</td>
</tr>
<tr>
<td>Gas prices/oil prices</td>
<td>387</td>
<td>0.54</td>
<td>0.33</td>
<td>0.11</td>
<td>1.65</td>
</tr>
<tr>
<td>Oil energy independence</td>
<td>387</td>
<td>9.73</td>
<td>18.44</td>
<td>0.12</td>
<td>98.98</td>
</tr>
<tr>
<td>Coal energy independence</td>
<td>387</td>
<td>17.92</td>
<td>26.75</td>
<td>0.00</td>
<td>103.12</td>
</tr>
<tr>
<td>Gas energy independence</td>
<td>387</td>
<td>7.02</td>
<td>9.86</td>
<td>0.00</td>
<td>42.49</td>
</tr>
<tr>
<td>Carbon free energy independence</td>
<td>387</td>
<td>17.60</td>
<td>12.40</td>
<td>0.30</td>
<td>47.07</td>
</tr>
</tbody>
</table>
## Table 2: Estimation results

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln(GDPpc)</td>
<td>0.446**</td>
<td>0.816***</td>
<td>0.537***</td>
<td>0.625***</td>
<td>0.554*</td>
</tr>
<tr>
<td>ln(GDPpc)^2</td>
<td>-0.038</td>
<td>-0.115***</td>
<td>-0.054</td>
<td>-0.037</td>
<td>-0.034</td>
</tr>
<tr>
<td>ln(Oil prices)</td>
<td>-0.055**</td>
<td>0.055*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ln(Coal prices)</td>
<td></td>
<td></td>
<td>-0.117***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ln(Gas prices)</td>
<td></td>
<td></td>
<td>-0.074***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ln(coal/oil prices)</td>
<td></td>
<td>-0.095***</td>
<td>-0.089***</td>
<td>-0.053***</td>
<td></td>
</tr>
<tr>
<td>ln(gas/oil prices)</td>
<td></td>
<td>-0.056***</td>
<td>-0.066***</td>
<td>-0.017</td>
<td></td>
</tr>
<tr>
<td>ln(Oil energy independence)</td>
<td>-0.065***</td>
<td>-0.063***</td>
<td>-0.055***</td>
<td>-0.062***</td>
<td>-0.060***</td>
</tr>
<tr>
<td>ln(Coal energy independence)</td>
<td>-0.009</td>
<td>-0.007</td>
<td>-0.003</td>
<td>-0.009</td>
<td>-0.019**</td>
</tr>
<tr>
<td>ln(Gas energy independence)</td>
<td>0.012***</td>
<td>0.011***</td>
<td>0.007*</td>
<td>0.010***</td>
<td>0.004</td>
</tr>
<tr>
<td>ln(Carbon free energy independence)</td>
<td>-0.157***</td>
<td>-0.135***</td>
<td>-0.146***</td>
<td>-0.136***</td>
<td>-0.055***</td>
</tr>
<tr>
<td>constant</td>
<td>2.016***</td>
<td>1.789***</td>
<td>1.240***</td>
<td>0.768**</td>
<td>1.073***</td>
</tr>
</tbody>
</table>

- Observations: 387, 387, 387, 387, 387
- R2_within: 0.52, 0.575, 0.651, 0.845
- Adjusted R2: 0.493, 0.575, 0.603, 0.816
- LM test of cross-section independence: 5.053 (0.000), 4.675 (0.000), 7.726 (0.000), 1.168 (0.243), 1.544 (0.123)

<table>
<thead>
<tr>
<th></th>
<th>NO</th>
<th>NO</th>
<th>NO</th>
<th>NO</th>
<th>YES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country-trends Included</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Year-dummies included</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
</tbody>
</table>

Turning point: 34.7

* p<.1, ** p<.05, *** p<.01
### Table 3. Comparison between the linear model and the partially linear model

<table>
<thead>
<tr>
<th></th>
<th>(a) Linear model</th>
<th>(a) Partially linear model</th>
<th>(b) Linear model</th>
<th>(b) Partially linear model</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln(GDPpc)</td>
<td>1.661***</td>
<td>1.636***</td>
<td>0.554*</td>
<td>1.549***</td>
</tr>
<tr>
<td>ln(GDPpc)^2</td>
<td>-0.122*</td>
<td>-0.116*</td>
<td>-0.034</td>
<td>-0.099</td>
</tr>
<tr>
<td>ln(coal/oil prices)</td>
<td>0.076***</td>
<td>0.081***</td>
<td>-0.053***</td>
<td>0.076***</td>
</tr>
<tr>
<td>ln(gas/oil prices)</td>
<td>-0.175***</td>
<td>-0.179***</td>
<td>-0.017</td>
<td>-0.180***</td>
</tr>
<tr>
<td>ln(Oil energy independence)</td>
<td>-0.070***</td>
<td>-0.073***</td>
<td>-0.060***</td>
<td>-0.072***</td>
</tr>
<tr>
<td>ln(Coal energy independence)</td>
<td>0.122***</td>
<td>0.122***</td>
<td>-0.019**</td>
<td>0.122***</td>
</tr>
<tr>
<td>ln(Gas energy independence)</td>
<td>-0.001</td>
<td>0.000</td>
<td>0.004</td>
<td>0.001</td>
</tr>
<tr>
<td>ln(Carbon free energy independence)</td>
<td>-0.241***</td>
<td>-0.250***</td>
<td>-0.055***</td>
<td>-0.249***</td>
</tr>
</tbody>
</table>

Note: (a) no country-specific and year-specific effects, common nonparametric time trend. (b) country-specific effects and year-specific effects, country-specific nonparametric time trends.
Table A1: Unit root tests

<table>
<thead>
<tr>
<th></th>
<th>per capita CO₂</th>
<th>per capita GDP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>trend included</td>
<td>trend included</td>
</tr>
<tr>
<td>Ho: Panels contain unit roots</td>
<td>-1.879 (0.030)</td>
<td>-3.312 (0.000)</td>
</tr>
<tr>
<td>LLC</td>
<td>-1.370 (0.87)</td>
<td>-3.645 (0.000)</td>
</tr>
<tr>
<td>Ho: All panels contain unit roots</td>
<td>-1.850 ²</td>
<td>-2.745 ³</td>
</tr>
<tr>
<td>IPS</td>
<td>-0.322 ²</td>
<td>-1.514 ³</td>
</tr>
<tr>
<td>Fisher (Inverse normal)</td>
<td>-0.294 (0.385)</td>
<td>-3.048 (0.001)</td>
</tr>
<tr>
<td></td>
<td>2.880 (0.998)</td>
<td>-1.824 (0.034)</td>
</tr>
</tbody>
</table>

Notes: p-values in parentheses; ² Exact critical values: -2.050 (1%), -1.900 (5%), -1.820 (10%); ³ Exact critical values when trend is included: -2.680 (1%), -2.530 (5%), -2.450 (10%).
Figure 1: Observed versus fitted national CO₂ emissions per capita.

Source: own elaboration.
Figure 2: CO$_2$ emissions, GDP and energy prices.

Source: own elaboration.
Note: There is not truncation in the development process, so point A takes place earlier in time than point B. Otherwise the final point will be C, following a price increase without a rise on per capita GDP.
Figure A1. Residuals graphical analysis.