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The long-run relationship between CO_2 emissions and economic activity in a small open economy: Uruguay 1882 - 2010

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Abstract

The long-run relationship between carbon dioxide emissions from energy use and economic activity level is estimated for Uruguay between 1882 and 2010. We apply cointegration techniques and estimate a Vector Error Correction Model (VECM) for testing whether these variables are endogenous over the long-rung while also considering the short-run dynamics. The economic productive structure, the degree of openness, and the share of clean sources on total energy supply are also considered as explanatory variables. The results show that there exists a linear relationship between carbon dioxide emissions and per capita economic activity level. Moreover, emissions increase jointly with the industrial sector participation in total output, as a consequence of the intensity of this activity in the consumption of energy from fossil fuels sources. The degree of openness is inversely related with carbon dioxide emissions. This is so because the periods of major opening were based on primary inputs exports, lower in energy intensity than industrial products. The changes in carbon dioxide emission are inversely related to the variation in the share of clean sources on total energy supply. Finally, all the variables included in the cointegration vector are endogenous, adjusting together to the deviations from the long-run relationship. As a consequence of the above, economic growth appears to be not enough for diminishing Uruguayan emissions in the long-run. Changes in the energy matrix should be encouraged, and emissions reduction should come not by energy constraints but by the development of clean sources or energy use efficiency improvements, given the impact of energy on economic activity level.

Keywords: carbon dioxide, cointegration, Uruguay, Environmental Kuznets Curve

JEL codes: Q43, C32, Q56

1. Introduction

Since the early 1990s the debate on the relationship between economic growth and environmental degradation has been dominated by the discussion of the environmental Kuznets curve (EKC) hypothesis. The EKC suggests the existence of an inverted-U shaped relationship between environmental degradation and income per capita. According to Grossman and Krueger (1991) the EKC hypothesis is explained by three effects: i) the scale effect, the greater the scale the greater is the requirement of resources and waste generation, ii) the composition effect, a growing economy changes its economic structure allegedly towards less polluting activities after achieving certain income threshold, and iii) the technological effect: richer countries increase their capacity to face technological substitution towards less pollution processes. Thus, according to the EKC hypothesis, while the increase in the scale of an economy would contribute to increase environmental degradation, the growing importance of the other effects as the economy grows would lead to a turning point in the relationship. It should be noticed that this hypothesis assumes that both composition and technological effects work in the assumed direction, which could be not the case for all pollutants and economies (Roca and Padilla, 2003).

The relationship between income per capita and environmental pressure or degradation can be driven by different underlying factors. This relationship is usually represented by a reduced form model that could arise from different structural models and be the result of multiple determinants and relationships, which could also vary across countries and pollutants (Opschoor, 1995; Perman and Stern, 1999). The composition effect has been often approached by the inclusion of the share of the industrial sector in total output (Panayoutou, 1997; Shen, 2006; Piaggio, 2008) or the share of the tertiary sector (Friedl and Getzner, 2003). The industrial sector is usually associated to higher emissions than the primary and tertiary sectors because of its higher energy intensity. In this way, it is expected that the emissions per unit of output decrease when the structure of the economies change from industry to services. The technological effect has been often approached by the inclusion of a deterministic trend (Panayoutou, 1997) and the share of different energy sources (Roca et al., 2001; Iwata et al., 2010).

Moreover, the EKC can also be the result of the displacement of polluting activities from rich to poor countries, a behavior that may not be replicated in the future by present poor countries (Stern et al., 1996; Cole et al., 1997). This may be reflected in a positive relationship between emissions and trade in those countries where polluting activities tend to locate, and a negative relationship in those countries that displace the polluting activities. However, there is no consensus about this. If exports are driven by low-polluting activities (like agrarian products), the relationship between emissions and trade can be the inverse. The role of trade in the relationship between emissions and income has been usually approached by the degree of openness (Grossman and Krueger, 1991; Cole et al., 1997; Friedl and Getzner, 2003; Piaggio, 2008; Haciloglu, 2009; Leitão, 2010; He and Wang, 2012).

Empirical studies on the EKC often analyze only emissions in per capita terms. However, the relevant level of pressure for nature is total pressure and not per capita pressure as Luzzatti and Orsini (2009) argue for the case of energy use. In the case of carbon dioxide emissions, the pressure on the environment depends on global emissions, while the variable in per capita terms is only an indicator of the relative contribution and so the responsibility of the inhabitants of different parts of the world. Certainly, the use of the per capita variable has the advantage of giving results directly comparable across countries, but its interpretation widely differs from the one when the absolute value of emissions is considered.[1] A similar concept has been used in the literature for the distinction between relative and absolute decoupling (or weak and strong delinking), referring to variables of environmental pressure intensity (pressure per unit of product) (Opschoor, 1995). An inverted-U shaped relationship between pollution and economic activity in per capita terms cannot be interpreted as evidence that economic growth is sufficient to induce environmental improvement or that the ecospace is large enough to support ongoing economic growth, as this will ignore the impact of population growth.

Earlier studies also ignored that both the functional form and the parameters of the relationship between environmental degradation and income can be different across countries (e.g., Grossman and Krueger, 1991 and 1995; Shafik and Bandyopadhyay, 1992; Selden and Song, 1994). However, there is neither theoretical nor empirical support for the assumption of equal functional forms and parameters in this relationship across different countries (Perman and Stern, 1999 and 2003; List and Gallet, 1999; Martínez-Zarzoso and Bengochea-Morancho, 2003 and 2004; Dijkgraaf and Vollebergh 2005; Dijkgraaf et al., 2005; Piaggio and Padilla, 2012). Countries with similar economic activity level can follow different paths. As a consequence, de Bruyn et al. (1998) argued that more attention should be paid to the behavior of individual countries in order to assess the possible impacts of the increase in economic activity on environmental quality for each country. Since the late 1990s several analysis of the EKC at national level emerged (see e.g., Vincent, 1997; Moomaw and Unruh, 1997; de Bruyn et al., 1998; Lekakis, 2000; Roca et al., 2001; Friedl and Getzner, 2003; Shen, 2006; Halicioglu, 2009; Piaggio, 2008; Song et al., 2008, Wang, 2009; Iwata et al., 2010; Menyah and Wolde-Rufael, 2010; Jalil and Feridum, 2011; Esteve and Tamarit 2012a, 2012b; Vaona, 2012; Stern and Enflo; 2013; Sephton and Mann, 2013).

Most of the studies estimate a long-run relationship between environmental degradation or energy use and economic level activity with time periods no longer than 60 years, because of data constraints. Energy (and hence carbon dioxide emissions) transitions are structural facts, and hence they should be analyzed in a long-term scope. There are a few previous works that look to the relationship between energy consumption or pollution and economic activity level for long periods. Decomposition techniques have been employed by Kander and Lindmark (2004) in Sweden; Bartoletto and Rubio (2008) in Italy and Spain; and Tol et al. (2009) in the USA. Moreover, multi-equation models and cointegration analysis have been employed by Esteve and Tamarit (2012a, 2012b) and Sephton and Mann (2013) in Spain; Vaona (2012) in Italy; Barassi and Spagnolo (2012) in Canada, France, Italy, Japan, UK, and USA; and Stern and Enflo (2013) in Sweden.

The present paper analyzes the relationship between CO_2 emissions from energy use and economic activity in Uruguay during the period 1882–2010. This is one of the largest time spans used in the literature, in particular for a developing country case. Moreover, the country has experienced a high variability in its per capita income over this period, which would facilitate to detect the influence of these variations on environmental pressure. Uruguay is a small open economy with a strong specialization in the primary sector, mainly in agricultural

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[1] Even for this purpose, as Luzzati and Orsini (2009, p. 292) argue, in the case of panel data or cross-section analyses, "*comparability would be better obtained by standardizing environmental indicators with a scalar (e.g. inhabited area, population in a given year), rather than a variable, i.e., population time series*". In any case, as we only study the case of Uruguay, using the variable in per capita terms would give us results more directly comparable with the results of previous studies.

products. The Uruguayan case has been previously studied by Piaggio (2008) for a much shorter period (1950–2000). The present study not only extends the time length of analysis, but also includes other relevant determinants to be considered. This would allow either to confirm previous results, or to check if in the very long-run there are other factors driving this relationship that are not present in a shorter period (or viceversa).

We analyze the dependent variable (CO_2 emissions) both in absolute and per capita terms. We employ cointegration techniques to determine the existence of a long-run relationship between non-stationary variables, and a Vector Error Correction Model (VECM) is estimated for allowing variables to be endogenous. This allows to overcome the critique made by Arrow et al. (1995), who argue that early studies ignored the possible feedback between income and the environmental indicator. Endogenous variables in the long-run would mean that not only carbon dioxide emissions are explained by economic growth, but that it could also be in the other way around. This has important policy implications, given that a reduction of fossil energy consumption to mitigate emissions could impact on the economic growth unless energy efficiency is improved, or this energy is substituted by clean sources.

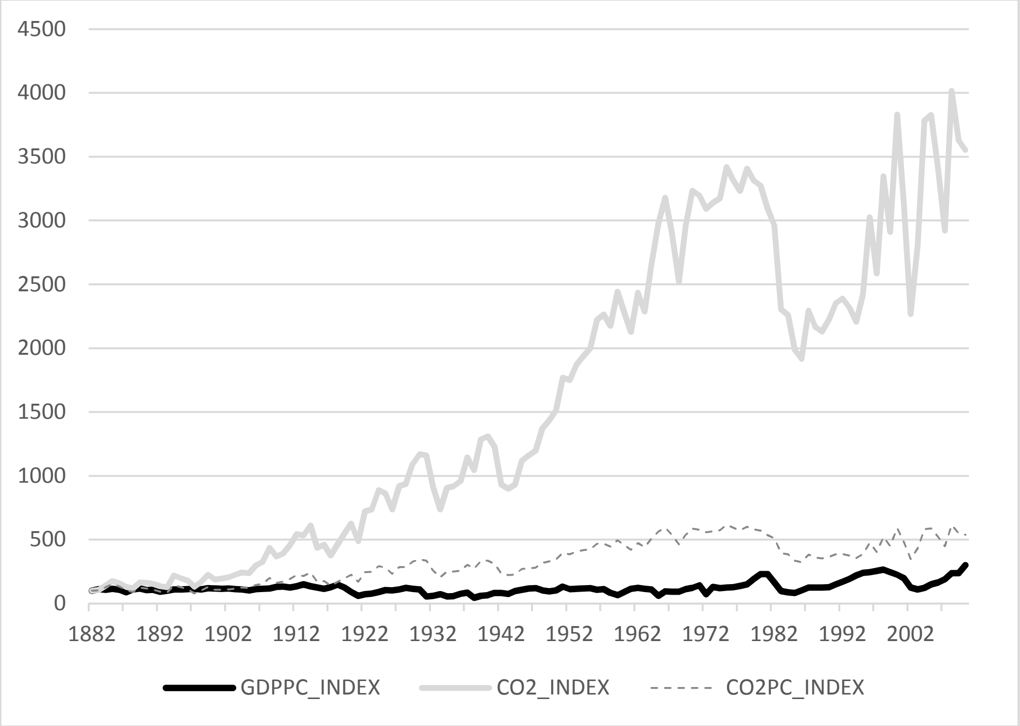
Other explanatory variables in the long-run relationship that are important for the Uruguayan case are included. The transformations in the productive structure and the international integration patterns have driven changes in the uses of energy. In order to consider the effect of these factors in explaining the relationship between carbon dioxide emissions and economic activity, we use two indicators that measure the structural change (the share of the industrial sector in the economy, and a structural composition indicator). The degree of openness of the economy and the share of clean energy sources are also considered in the analysis.

The rest of the paper is organized as follows. Section 2 narrates the evolution of the variables of interest in Uruguay during the last 130 years. Section 3 explains the model specification and the empirical strategy. Data is described in Section 4, and Section 5 presents the results. Finally, Section 6 includes the discussion, main conclusions and the research agenda.

2 An historical overview of the Uruguayan economy

It is of particular interest to the aim of this paper to give some stylized facts about the long-run economic performance and the characteristics of the energy system of Uruguay. In the long-run the per capita GDP grew at a quite low rate (1.3% annual rate of growth over 1882–2010). Phases of rapid growth were followed by deep crises, explained as a cyclical pattern correlated with the volatility of the terms of trade, the world demand and international capital flows (Bértola, 2008). Figure 1 describes a divergent path between the carbon dioxide emissions in absolute and per capita terms. It is clear that, while per capita emissions behave very similar to GDP per capita, the pollution in absolute terms shows a gap with them. The first part of this gap can be explained by the evolution of population that presented different phases over these 130 years. After being very dynamic until the 1930s, population became stable in the following decades (immigration almost disappeared and population grew at a very low rates) and after the 1960s the country was a net-emigration region (Bértola, 2008).

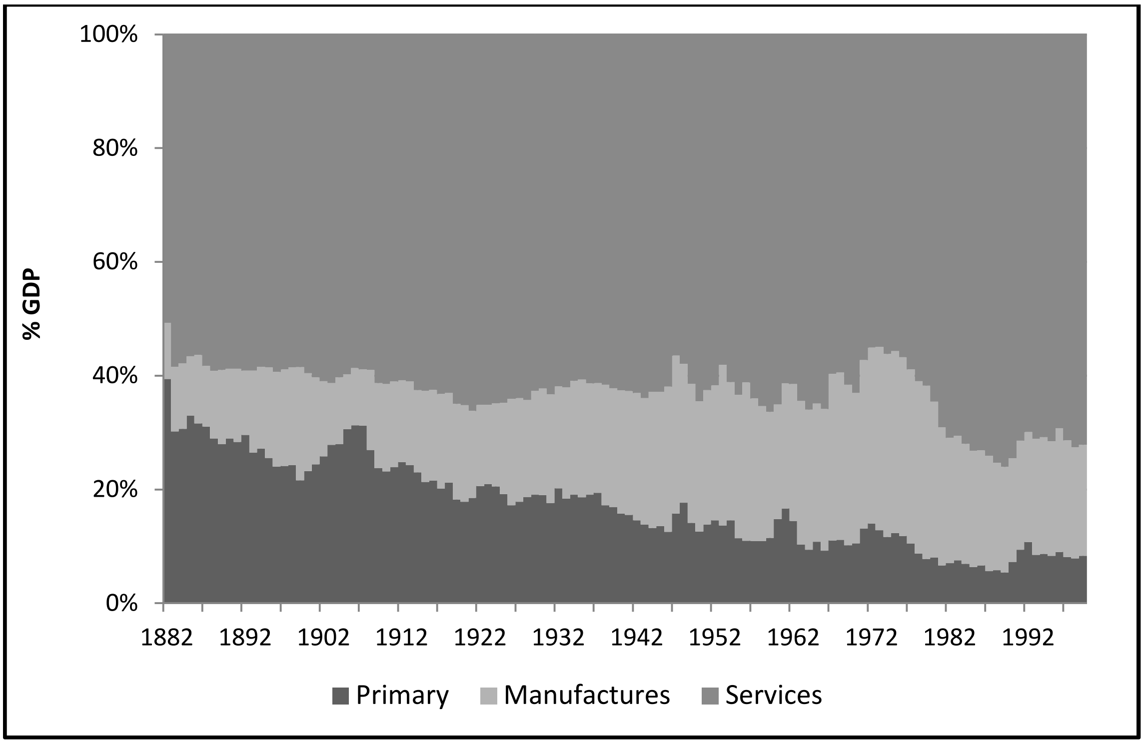
Figure 1: Carbon dioxide emissions, per capita carbon dioxide emissions and per capita GDP at 2005 constant Uruguayan pesos (Index 1882=100), 1882-2010.



Source: own elaboration based in Bonino et al. (2012) and Bertoni and Román (2013)

These divergent paths may also be explained by changes in the Uruguayan productive structure over the last century. Economic history identifies three phases of development patterns (Bértola and Porcile, 2000; Bértola, 2008). During the first globalization, between the late 19th century and the 1930s, growth was led by exports based on a few primary products, and the country achieved high income levels in international comparative terms. The primary sector represented about one-third of total economic activity between 1870 and 1930 while the share of the industrial sector was around 15% of GDP (Figure 2). As a consequence of the Crash of 1929 and the Great Depression, the country adopted inward-oriented policies and the Import Substitution Industrialization (ISI) or State-led Industrialization as a strategy to promote growth. The industrial sector increased its importance in total output, reaching almost one-third of total GDP, contrary to the declining participation of agriculture. The post Second World War decades were of rapid growth, led by the manufacture industrial dynamism that lasted until the late 1950s when the country faced a period of stagnation and high inflation (Bértola, 1991). This episode was not overcome until the seventies with deep changes, increasing openness and financial liberalization and regional trade agreements. A new strategy to promote the expansion of manufacture exports was implemented, and the industrial sector maintained its participation in the economy but with a very unstable evolution. The liberal process became intense since the 1990s and the manufacturing sector reduced drastically its contribution to the economy. Some authors identify this process as a deindustrialization period (Bértola 2008, Bértola and Bittencourt, 2005). Although the economy recovered its dynamism, it went through new deep crises (followed by recoveries) as the ones that happened in the beginning of the 1980s and the 2000s, respectively.

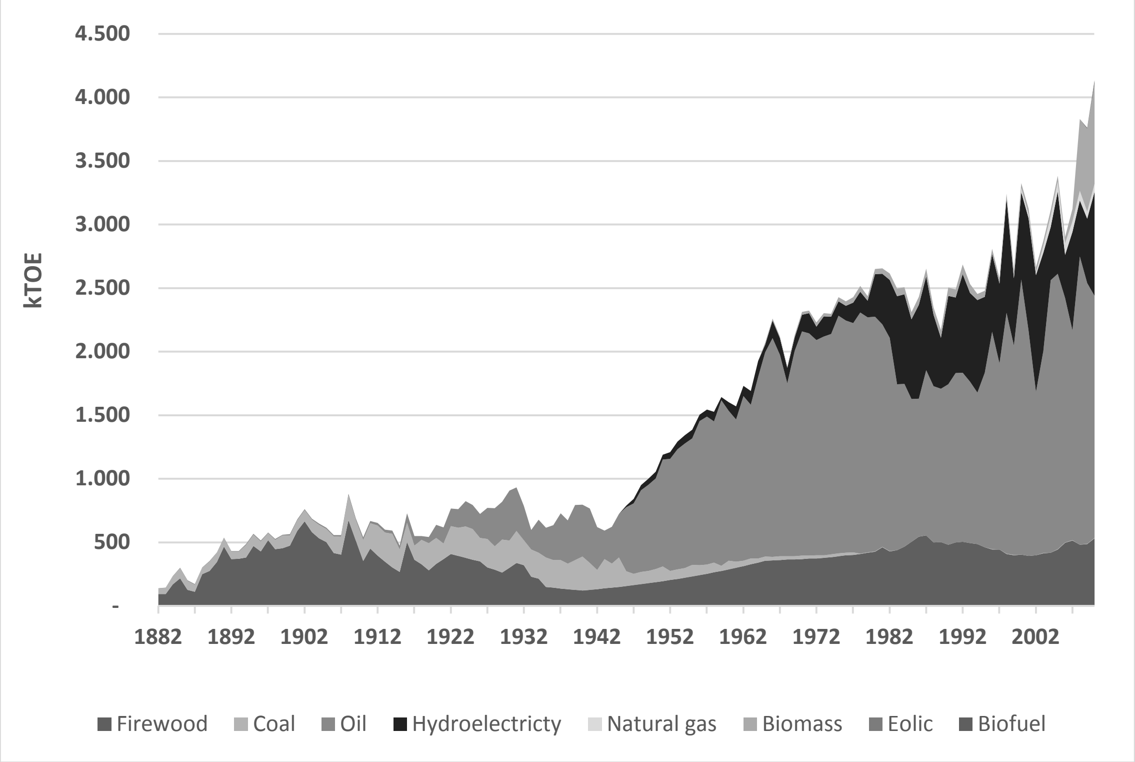
Figure 2: Uruguayan productive structure: value added by activity (% of total value added), 1882-2010.



Source: own elaboration based on Bonino et al. (2012)

Uruguayan exports have been historically concentrated on primary products such as cattle and crops (Willebald and Bértola, 2013; Duque and Román, 2007). In addition to this dependence on primary products, the country as a small economy in the international markets has been highly affected by the movements in international prices, especially the prices of commodities (Bértola, 2008). Another important fact is the high dependence of the Uruguayan energy system on fossil fuel. The main feature of the energy transition in this economy (Figure 3) has been the shift from traditional and domestic energy sources (firewood, muscle energy) to modern and external carriers (coal, oil and natural gas) as the country lacks domestic reserves of fossil fuel (Bertoni, 2011; Bertoni and Román, 2013). The processes of structural change and international integration have driven changes in the uses of energy. For example, the introduction and diffusion of the railways in the late 19th and earlier 20th century, and the development of the industrial activities and the technical system associated with electricity demanded fossil energy during the first half of the 20th century (Bertoni and Román 2013). Coal was the main fossil fuel until the 1920s-1930s, when it was replaced by oil in a persistent but not linear process. Hydro-electricity appeared in the second half of the 20th century and although it increased its share in the energy matrix it did not overpass oil as the main important fuel of the economy.

Figure 3: Uruguay sources of primary energy supply (kTOE), 1882-2010.



Source: own elaboration based on Bertoni (2011) for 1882-1964, and *Balance Energético Nacional*, Dirección Nacional de Energía, Ministerio de Industria, Energía y Minería for 1965-2010.

It is clear from the above that the dynamic changes of the economic structure and its international integration have driven changes in the uses of energy. The increase of the industrial activity share is expected to be positively related with an increase in emissions over time. Industry was promoted jointly with the introduction of coal first (replacing firewood) and oil after (replacing coal) as the principal energy sources. In addition, this sector is much more energy intensive than other activities. In this way, any increase in the industrial share would mean more emissions as consequence of the energy use. The decades of greater openness in Uruguay were periods of specialization in the export of primary products, in response to favorable international contexts, and the share of manufactures did not increase. On the contrary, the manufacture sector either maintained its participation –during the First Globalization- or reduced its relative importance –since the 1980s-. As a consequence, the degree of openness is expected to be inversely related with carbon dioxide emissions, other things equal.

3. Model specification and empirical strategy

The relationship between environmental degradation and economic activity is analyzed departing from a reduced-form model. Therefore, as an empirical phenomenon, it can be the result of one or more different structural relationships. Hence, this is in fact an analysis of the apparent relationship between environmental degradation and economic activity. In line with previous works, the reduced-form model relates carbon dioxide emissions with economic activity level (which can follow a lineal or a quadratic functional form):

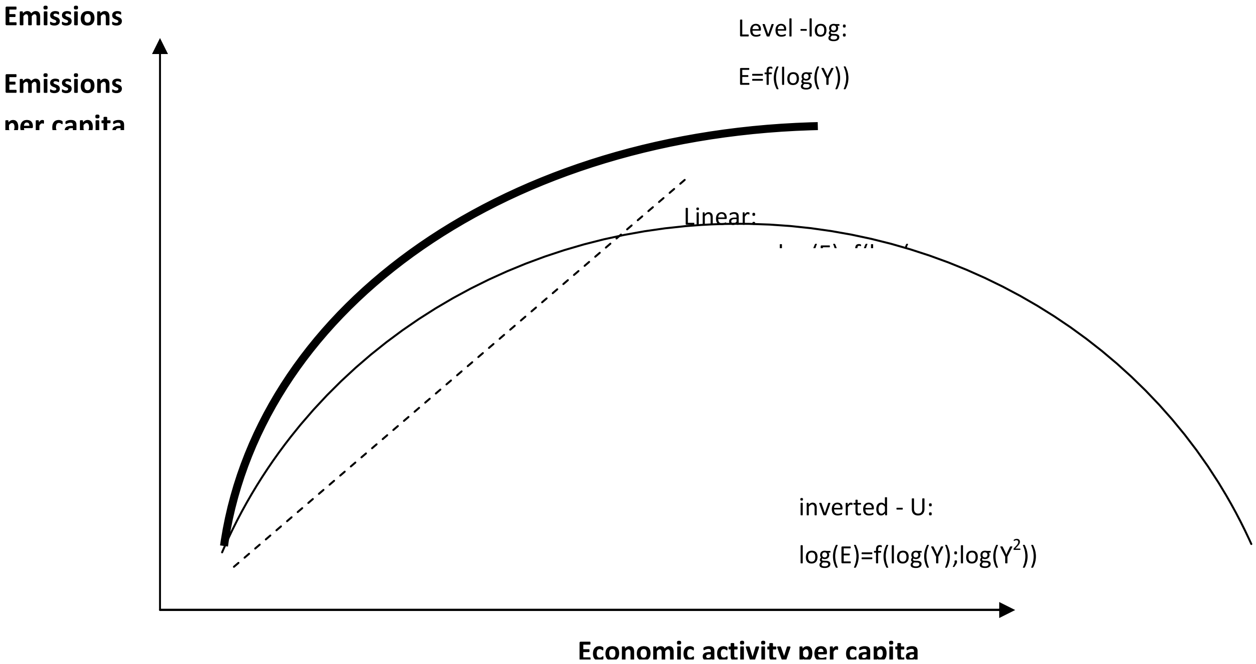
(1) $E_t = \alpha_i + \beta_1 Y_t + \beta_2 Y_t^2 + \varepsilon_t$

E_t denotes carbon dioxide emissions, Y_t is income per capita in period $t=1, ...T$, and ε_t is the error term normally distributed. The correct functional form for each country can be specified from the equation above. An inverted-U relationship is denoted by $\beta_1>0$, $\beta_2<0$.

The functional form between carbon dioxide emissions and economic activity is not clear in advance. In general, variables are taken in natural logarithms. This transformation is a good approach to model series variation rates, and hence the estimated parameters can be interpreted as elasticities. Moreover, it allows to stabilize the data variance, and to amend the existence of positive symmetry in the data. However, this transformation must be supported in theoretical assumptions, and must be empirically tested. This step is usually skipped in the literature that works on the relationship between the environment and economic activity. However, this is an important issue, because this relationship can follow different paths that would be omitted when automatically employing this transformation. For our purpose, three specifications are of interest (Figure 4). We employ natural logarithms for a linear and an inverted-U specification. This depicts the black lines in Figure 4, and are the specifications commonly employed in the literature. The first one depicts a constant growing relationship between both variables, while the second one means that there exists a threshold from which, once crossed, emissions start to decrease with economic activity increases. There may be the case that the threshold is not reached by countries, but the increase in emissions per unit of output is not constant. This would be better reflected by a level - log functional form (as depicted by the bold line in Figure 4). This can be estimated just by applying the natural logarithms transformation to the explanatory variables, but interpretation of the coefficients must be different than in the case of the log - log specification. While in the log - log specifications the beta parameters are interpreted as elasticities (a 1% change in Y means a $\beta\%$ change in E), in the level - log specification a 1% change in Y means a $\beta/100$ units change in E.

The model in Eq. (1) depicts an apparent relationship between carbon dioxide emissions and economic activity. But as explained in the introduction, this relationship can be driven by several factors that can be explained by other determinants of carbon dioxide emissions. In this paper we extend the model in Eq. (1) including three more determinants. First, the composition effect is approached by two alternative indicators: the share of the industrial sectors in economic activity and a structural composition index. Second, we include a measure that approaches the openness of the economy (the ratio between the sum of exports and imports over total economic activity). The technological effect is captured allowing a linear trend in the data (though this may also capture the effects of other variables related with time).

Figure 4: Functional forms



Finally, Arrow et al. (1995) criticized the first approaches in the estimation of this relationship for ignoring the feedback between the variables. Because of this possibility, we study the relationship between carbon dioxide emissions and economic activity through a multi-equation model, allowing the variables to be endogenous. This means that not only carbon dioxide emissions can be explained by the economic activity level, but that the relationship could also be in the other way. When the emissions are mainly consequence of the energy consumption of productive activities, they turn into an input for income generation (Barassi and Spagnolo, 2012). In this way, environmental policies simply restricting the use of energy can represent a constraint for the economy. Empirical works approach the feedback through Granger causality tests (Coondoo and Dinda, 2002; Dinda and Condoo, 2006; Dedeoğlu and Kaya, 2013), simultaneous equations (Hung and Shawn, 2004; Shen, 2006; Omri, 2013) and vector-autoregressive (VAR) or vector error correction models (VECM) (Halicioglu, 2009; Piaggio, 2008; Barassi and Spagnolo, 2012; Esteve and Tamarit, 2012b; Vaona, 2012; Borozan, 2013; Septhon and Mann, 2013). Stern and Enflo (2013) employ several of the techniques at the same time.

In this paper we estimate a VECM (Banerjee et al., 1993), which allows to estimate the long-run relationship between non-stationary series, and their short-run relationship. Early works in the analysis of the relationship between environmental degradation and economic activity ignored the stationarity properties of the series (Grossman and Krueger, 1991 and 1995; Shafik and Bandyopadhyay, 1992; Carson and Mccubbin, 1997; Cole et al. 1997; Vincent, 1997; and de Bruyn et al., 1998). Because both carbon dioxide emissions and economic activity series use to be non-stationary (their parameters are not constant over time) this could have led to the estimation of spurious relations. Therefore, the estimation of a long-run relationship employing the variables in levels —without any stationary transformation— would result in non-robust estimators (making not possible to apply inference tests) unless the series were cointegrated (Enders, 2004).

We first study the stationary properties of the series through the Augmented Dickey-Fuller unit root test (Dickey and Fuller, 1981). This determines which series are stationary and which are not. The non-stationary series are included as endogenous variables in the cointegration relationship, while the stationary ones are included as explanatory variables in the short-run relationship. Cointegration is tested by a multi-equation model as proposed by Johansen (1991). The VECM is defined departing from a vector of endogenous variables X_i, where $i=1...N$ denotes each of the variables included:

$$\Delta X_{it} = A_1 \Delta X_{it-1} + ... + A_k \Delta X_{it-k} + \Pi X_{it-k} + \mu + \Gamma_1 Z_t + \Gamma_2 D_t + \varepsilon_t \quad t = 1,...,T \tag{2}$$

Where $\varepsilon_t \sim N(0, \sigma^2)$, μ is a constant vector, and Z_t is a vector containing exogenous variables (that are stationary and do not take part in the cointegration relationship). Finally, sometimes there are big changes in data explained by extraordinary events. Because of that, D_t, a vector that contains dummy variables, is included for conducting an intervention analysis (Hendry and Juselius, 2000). We conduct an intervention analysis for capturing series extraordinary and particular events until the joint residuals of the model turn normally distributed. This allows to make valid inference tests on the parameters.[2]

The information about the long-run relationship is contained in matrix $\Pi = \alpha\beta$, where β is the vector of coefficients of the existing long-run relationships, and α is the vector of coefficients of the long-run adjustment mechanism. The rank of matrix Π is going to determine the number of cointegration relationships that exists among variables. If vector X_i contains N endogenous variables, then N-1 cointegration relationships could exist. After the cointegration analysis is developed, exclusion tests are conducted (significance test on the β parameters). This allows to test which variable takes part in the long-run relationship. If a non-stationary variable is not significant in the long-run relationship, a stationary transformation of it can be included as an exogenous variable explaining the short-run dynamics. Weak exogeneity tests are conducted over the α parameters to check which variables adjust to the deviations from the long-run relationship. Both tests are conducted by Likelihood Ratio statistics between the restricted and non-restricted models. After the long-run relationship is analyzed, the endogenous variables short-run dynamics are studied looking at the A_i of Eq. (2).

4. Data

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[2] A VECM with n endogenous variables provides a measure of the normality of the residuals for each of the n single equations, as well as a measure for the whole model. When a quadratic transformation of the economic activity level is included, the behavior of the residuals on corresponding to this equation is ignored. Moreover, we only check the normality of $n-1$ remaining equation, as well as the normality of the model as a whole. Explaining this variable is not of interest at all, and is only included because the VECM specification. In this way, despite the joint normality test may be rejected, we make sure that it is not rejected for the other equations taken alone.

The time series covers the period 1882–2010 as the available energy data starts in 1882. Together with the variable definitions and sources we used it is important to take into account some general remarks about the quality of the dataset.

The macro variables (GDP, value added of the industrial sector, exports and imports) are most reliable from 1955 onwards as they are taken from the System of National Accounts (SNA). For the previous period, 1882–1955 they are historical estimations, and therefore present the expected limitations of the reconstructions of macro variables for pre-statistical periods. As a measure of real income per capita we use the gross domestic product (GDP) at constant prices expressed in Uruguayan pesos of 2005. The data are taken from Bonino et al. (2012) which in turn used the following sources to estimate long-run series. The information from 1955 onwards corresponds to the official SNA published first by Banco de la República (1965) and afterwards by Banco Central del Uruguay in several publications. The data back to 1870 are historical estimations made by Bertino and Tajam (1999) for the period 1900–1955, and the data from 1870–1900 were elaborated by Bértola et al. (1998).

The population figures for 1937–2010 are from *Instituto Nacional de Estadística* and in order to go back to 1879 we used the historical estimations from *Programa de Historia Económica y Social*.[3] The industrial share in the economic activity is calculated as the contribution of manufacturing and construction sectors in GDP (both variables originally expressed in pesos at current prices). This ratio is obtained from Bonino et al. (2012) which use the same sources as the ones described for the GDP. The Structural Composition Indicator (SCI) was constructed by Bonino and Willebald (2013) and consist of synthetic indicator which depicts the transformation in the productive structure.[4] This indicator is a coefficient between 0 and 1, where 0 corresponds with the absence of structural change while values higher than 0 shows evidence of changes in the productive structure (taking as a reference the productive structure of 1870). The openness coefficient is the ratio of exports plus imports to GDP (all variables in Uruguayan pesos at current prices). These trade were calculated by Román (2013) based on several sources as detailed. Since 1955 onwards, exports and imports of goods and services were obtained from the SNA. For the pre-national accounts period, the information available is restricted to goods trade and was obtained from Bonino et al. (2015), Finch (1980) and Acevedo (1933, 1934).

In the case of the Uruguayan economy, carbon dioxide emissions (CO_2) are generated by the fossil fuel consumption of two main energy carriers: coal and oil. In order to estimate the quantity of CO_2 annually generated, firstly all energy is expressed in joules and, secondly, emission factors by fuel type were applied. In the case of oil, 74 grams of CO_2 are emitted every mega joule (MJ) used and the emission factor for coal is 92 grams of CO_2 per MJ. The long run series of coal and oil were obtained from Bertoni and Román (2013). The official information starts in 1965 with the national energy balance elaborated by the *Dirección Nacional de Energía*, which brings indicators of the gross energy supply by primary sources. In the lack of information for the previous period, Bertoni and Román (2013) present historical series of coal and oil consumption based on published data for 1937–1965 (Oxman, 1965) and on their own

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[3] http://www.ine.gub.uy. Data Base from Programa de Historia Económica y Social, Facultad de Ciencias Sociales, Universidad de la República.

[4] Bonino and Willebald (2013) compute the Structural Composition Indicator (SCI) for the period 1870-2011 based on trigonometric notions which combine annual data for seven sectors: Agriculture, Manufacturing, Construction, Utilities (Electricity, gas and water), Transport and communications, Government, and a residual which gathered the other activities. The data for their calculations are the sectorial value-added time-series from Bonino et al. (2012)

estimation of the apparent consumption of energy for the earlier decades (1879–1937). This data was also employed to estimate the share of clean sources on the energy supply.

5. Results

Variable *E* in the different models represents carbon dioxide emission. As explained before, four variations of this variable are going to be employed: CO_2, CO_2 *per capita*, $ln(CO_2)$, and $ln(CO_2$ *per capita)*. The unit root test has been conducted for all the considered series allowing a maximum of 4 lags (this is an extraordinary long length when working with annual data). The results show that all the series are non-stationary (Table A1 in the Appendix). However, *Share clean* variable (the share of clean sources on total energy supply) is non-stationary because it shows a structural break during 1900–1940, not showing a trend or a big variation in its variance. Therefore, we treat this variable as stationary with a structural break, being its first difference stationary both in mean and variance. The vector of endogenous variables in Eq. (4) is defined by $X_t = \{E_t, ln(GDP\ per\ capita)_t, Productive\ structure_t, Opennes\ coefficient\ _t\}$, where *Productive structure* is measured by two different indicators: *Industry share on GDP* and *Structural composition indicator*. *Share clean* is considered as exogenous, only related with the first difference of the endogenous variables. A quadratic transformation of economic activity is also included in the model for testing the inverted-U shape.

Looking into detail to the unit root series, all of them are non-stationary also in the presence of a significative linear trend. Because of this, Eq. (3) is specified under the assumption of an unrestricted constant term in the autoregressive vector but no linear trends in the cointegration relationship (denoted as case 3 in Hendry and Juselius, 2000). This is consistent with the presence of a linear trend in the long-run relationship that affects both, carbon dioxide emissions and economic activity level, but these trends cancel when included in the cointegration relationship (Hendry and Juselius, 2000). This linear trend in the cointegration relationship has been interpreted as the technological progress (Mazzanti and Musolesi, 2011). There is no sense in allowing a linear trend in the short-run relationship because it would not be plausible for first differences of carbon dioxide emissions and GDP per capita (it is very difficult to justify that growth rates constantly increase over time). In addition, we only allow one lag in the short-run dynamic (*t*=1). This is because we are working with annual data, and allowing more lags will difficult their plausibility and interpretation. Given these assumptions, the estimated model is formally defined as:

$$(3)\ \left\{\begin{matrix} \Delta E_t \\ \Delta ln(GDP\ per\ capita)_t \\ \Delta Productive\ structure_t \\ \Delta Open\ _t \end{matrix}\right\} = A_1 \left\{\begin{matrix} \Delta E_{t-1} \\ \Delta ln(GDP\ per\ capita)_{t-1} \\ \Delta Productive\ structure_{t-1} \\ \Delta Open\ _{t-1} \end{matrix}\right\} + \Pi \left\{\begin{matrix} E_t \\ ln(GDP\ per\ capita)_t \\ Productive\ structure_t \\ Openess\ coefficient\ _t \end{matrix}\right\} + \mu + \Gamma_1 share\ clean_t + \Gamma_2 d_t + \varepsilon_t$$

Table 1 summarizes the main results for the long run relationship. A linear relationship between carbon dioxide emissions (in per capita and absolute terms) and economic activity per capita is found. In addition, an increase in the share of the industrial sector in total GDP is positively correlated with carbon dioxide emissions, consequence of the greater energy intensity of these sectors. The same relation is obtained when the structural composition indicator (SCI) is used as measure of the modifications in the productive structure. The evolution of this coefficient brings evidence of structural changes taking as a reference the productive structure of 1870, which was mainly agrarian. Therefore, an increase of this coefficient can be understood as an industrialization process. This result is in line with Shen (2006) for China, and also Friedl and Getzner (2003) who find a positive coefficient in emissions for the share of services sectors in GDP (that is complementary to the industrial share in GDP) for Austria. This variable was not significant in Piaggio (2008) for the period 1950–2000 for Uruguay. Panayoutou (1997) and Leitão (2010) find a similar result for several countries in reference to sulfur dioxide emissions.

The degree of openness of the economy is inversely related with carbon dioxide emissions from energy. This is explained because the periods when the Uruguayan economy openness increases is based on primary products specialization and exports. These products have low intensity in carbon dioxide emissions. Similar result for the impact of the degree of openness in carbon dioxide emissions has been found by Friedl and Getzner (2003) in Austria who find a negative coefficient for the ratio of imports over GDP, and Piaggio (2008) for the degree of openness in Uruguay during a shorter period. The results are also consistent with Grossman and Krueger (1991) and Leitão (2010) in reference to sulfur dioxide emissions in a panel of 42 and 94 countries respectively. The opposite result was estimated by Haciloglu (2009) for Turkey for the degree of openness and by He and Wang (2012) for 74 Chinese cities for the ratio of foreign capital to total capital stock, both countries with openness processes based on industry.

Table 1: Long-run relationship VECM

		Extensive				Intensive			
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		CO_2	*CO_2*	*ln(CO_2)*	*ln(CO_2)*	*CO_2 per capita*	*CO_2 per capita*	*ln(CO_2 per capita)*	*ln(CO_2 per capita)*
ln(GDP per capita)		4.12E+07 **	12097215 **	9.14 ***	4.58 ***	12.80 ***	2.81 ***	6.45 ***	2.75 ***
s.d.		*5.61E+06*	*3128813*	*1.554635*	*9.59E-01*	*1.798603*	*8.17E-01*	*0.902807*	*5.73E-01*
% Manufacturing in GDP		7.46E+07 *		23.84237 **		25.45 **		16.25 **	
s.d.		*3.00E+07*		*8.285964*		*9.53E+00*		*4.800979*	
SCI			2.87E+07 *		8.61 *		6.91 **		4.63 *
s.d.			*6592258*		*2.07E+00*		*1.7006*		*1.22E+00*
Openness coefficient		-9.16E+07 *	-60087783 **	-20.09 ***	-15.21 ***	-32.79 ***	-15.94 ***	-15.00 ***	-10.31 ***
s.d.		*2.02E+07*	*12934597*	*5.474817*	*3.70E+00*	*6.75E+00*	*3.1667*	*3.249332*	*2.25E+00*
constant		2.43E+08	79053772	66.27	41.69	76.71	19.36	36.94	16.88
nº observations		128	128	128	128	128	128	128	128
Joint Akaike IC		16.37	17.62	-13.04	-11.46	-12.60	-11.64	-12.93	-11.86
Joint Schwarz criterion		18.95	20.29	-10.46	-9.06	-10.64	-9.14	-10.35	-8.92
Jarque-Bera joint normality test		10.39	12.08	13.70	11.32	12.85	6.87	15.43	9.33
p-value		*0.24*	*0.1479*	*0.09*	*0.18*	*0.12*	*0.551*	*0.0514*	*0.31*
Johansen cointegration test									
Cointegrating equations at 0.05 level	Trace statistic	1	1	1	1	1	1	1	1
	Max-Eigenvalue statistic	1	1	1	1	1	1	1	1

Notes: ***,**,* significant at 1%, 5% and 10% respectively. VECM specification with linear trend in the cointegration relationship and 1 lag.

We find very similar results when working with and without the natural logarithm transformation of carbon dioxide emissions. For testing the best functional form, we conduct uni-equation models were an adjusted transformation of carbon dioxide emissions in levels and logarithms is regressed against $ln(GDP\ per\ capita)$. In order to compare the goodness of fit of models in which the dependent variable is in logs or levels then an adjusted model must be constructed, because the Residual Sum Square (RSS) is not comparable between both models. For this, carbon dioxide emissions are standardized dividing it by its geometric mean (CO_2 adj). After that, the Box-Cox statistic to test the null hypothesis that both models are equal is conducted (Table 2).[5] The result shows that working with the logarithm transformation of the carbon dioxide emissions for modeling its relationship with the logarithm of GDP per capita gives very similar results that when not employing it. This means that if the rate of this relationship decreases over time, this is so small that can be approached by a linear (in the variables) model. In the VECM above we employed both transformations for checking the role of other determinants, but this result must be kept in mind when interpreting the final results.

Table 2: Uni-equation models

	CO_2 adj	***ln(CO_2 adj)***	***CO_2 per capita adj***	***ln(CO_2 per capita adj)***
ln(GDP per capita)	1.62 *	1.02 *	0.60 *	0.51 *
s.d.	*2.21*	*2.21*	*0.13*	*0.14*
constant	-8.43 *	-11.83 *	-3.85	-4.20 *
s.d.	*0.27*	*0.27*	*1.12*	*1.15*
RSS	151.12	150.13	38.85	41.0
N	132	132	132	132
Box-Cox	0.431		3.60	

Note: *, **, *** significant at 1%, 5% and 10% respectively.

The quadratic term of the economic activity level is significant but always depicts a U-shaped relationship (Table A2 in the Appendix). Moreover, when including the quadratic variable, the other determinants lose significance or show the opposite sign to the one that is expected. This means that including the quadratic term just brings distortion to the model, and should not be considered. In this way, an inverted U-shaped functional form is also discarded.[6]

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[5] The Box-Cox statistic is equal to N/2*log(RSSlargest/RSSsmallest) ~ $\chi_2(1)$). If the estimated value exceeds its critical value (from tables Chi-squared at 5% level with 1 degree of freedom is 3.84) the null hypothesis that the models are the same is rejected (i.e. they are significantly different in terms of goodness of fit).

[6] It was not possible to normalize the residuals of models (12) and (16) in Table A2 and A3 without an extremely large number of interventions. However, because of the results for all the other models, it is reasonable to reject the existence of an inverted U-shaped relationship for this specification too. It is also noticeable from Table A2 in the Appendix that when including the quadratic term of the economic activity level, a second cointegration equation appears to be significant in some cases. This is because even though the Johansen cointegration test (Johansen, 1991) is the most robust methodology for cointegration testing, it turns problematic when a non-linear transformation of the variables already present is included. Similar result has been shown by Haciloglu (2009). This second cointegration relationship has been ignored, given that is not of interest to explain the adjustments of the quadratic transformation of the per capita economic activity level.

Table 3 shows the cointegration term (α_i) and the coefficient associated to the *Share clean* variable from Eq. (5) for those models shown in Table 1. The cointegration term shows the right sign and is between 0 and 1 for all the variables. This means that the series do not react explosively in relationship to their deviations from the long-run relationship, turning back to the long-run relationship. This result is consistent with previous results in the literature employing multi-equation models. All the variables endogenously adjust to the estimated long-run relationship. In this way, not only the emissions are explained by the per capita economic activity level, the economic structure and the degree of openness, but the emissions also explain the deviations of these variables from the long-run relationship. However, the degree of openness and the structural decomposition index are weakly exogenous in models (3) and (8) respectively. Because of this, we cannot be conclusive for these variables in all the cases. The fact that the degree of openness is weak exogenous in model (3) can be explained because Uruguay is a very small country, for which trade is mainly driven by international prices, which are exogenous to the country. However, this is a particular case. As regards the SCI, it measures modifications in the production composition based on information of several sectors of the economy -not just the industrial sector- that can be less related to energy consumption. This can explain the difference in the significance of the cointegration term between models (4) and (8). However, both variables are endogenous in seven of the eight specifications, giving insight that they adjust together with the other variables to deviations from the long-run relationship.

Tables 3: Cointegration terms and *Share clean* coefficients in the short-run dynamics

Extensive

		(1)		(2)	
		CO_2		*CO_2*	
		CI term	**d(share clean)**	**CI term**	**d(share clean)**
d(CO_2)		-0.0031 ***	-2470269.0 ***	-0.0112 ***	-2594981.4 ***
s.d		*0.0019*	*529369.90*	*0.0044*	*495921.03*
d(ln(GDP per capita))		4.50E-09 *	0.0549	5.87E-09 ***	0.1751
s.d		*0.0000*	*0.2434*	*0.0000*	*0.2415*
d(% Manufacturing in GDP)		1.66E-10 ***	0.0063		
s.d		*0.0000*	*0.0249*		
d(SCI)				9.13E-10 **	0.0987 **
s.d				*0.0000*	*0.0491*
d(Openness coefficient)		-6.81E-10 *	-0.0138	-1.74E-09 ***	-0.0544
s.d		*0.0000*	*0.0730*	*0.0000*	*0.0664*
Lags		1		1	
		1		1	
Interventions	Scale	2002 2004 1983 1938 1931 1934 1960 1979 1885 1905 1921 1920		2002 2004 2006 2008 1983 1931 1892 1960 1920 1958	
	Shock	1972 1965 2007 2000 1996 1998 2005 1968 1911		1996 1998 2000 1972 1965 1938 1921 1894 1933 1968 1944 1889	

		(3)		(4)	
		ln(CO2)		*ln(CO2)*	
		CI term	**d(share clean)**	**CI term**	**d(share clean)**
d(lnCO_2)		-0.0062 **	-1.8413 ***	-0.0112 **	-1.8463 ***
s.d		*0.0032*	*0.1957*	*0.0059*	*-0.2006*
d(ln(GDP per capita))		0.0128 ***	0.1683	0.0259 ***	0.0517
s.d		*0.0037*	*0.2240*	*0.0070*	*-0.2383*
d(% Manufacturing in GDP)		0.0010 **	-0.0019		
s.d		*0.0004*	*0.0264*		
d(SCI)				0.0025 *	0.0965 **
s.d				*0.0015*	*-0.0507*
d(Openness coefficient)		-0.0013	-0.1663 ***	-0.0034 *	-0.1525 **
s.d		*0.0012*	*0.0708*	*0.0020*	*-0.0679*
Lags		1		1	
		1		1	
Interventions	Scale	1931 2002 1983 1934 1884 1979 1960 1958 1894 1920 1982 1915		1931 2002 1983 1892 1960 1934 1884 1920 2008	
	Shock	1972 1965 1938 1921 1908 1885 1916 1998 1897		1972 1965 1938 1921 1894 1915 1917 1908 1885 1998	

Intensive

		(5)		(6)	
		CO2 *per capita*		**CO2 *per capita***	
		CI term	**d(share clean)**	**CI term**	**d(share clean)**
d(CO_2 per capita)		-0.0043 *	-1.5435 ***	-0.0161 **	-1.2694 ***
s.d		*0.0028*	*0.2366*	*0.0078*	*0.2311*
d(ln(GDP per capita))		0.0135 ***	-0.0128	0.0229 ***	-0.1668
s.d		*0.0026*	*0.2238*	*0.0082*	*0.2456*
d(% Manufacturing in GDP)		0.0006 **	0.0186		
s.d		*0.0003*	*0.0269*		
d(SCI)				0.0032 *	0.0695
s.d				*0.0018*	*0.0534*
d(Openness coefficient)		-0.0024 ***	-0.0378	-0.0064 ***	-0.0229
s.d		*0.0008*	*0.0662*	*0.0022*	*0.0661*
Lags		1		1	
		1		1	
Interventions	Scale	1938 1931 1983 1960 1979 2002 1934 1921 2008 1920 2004		1892 2008 2004 1960 1982 1958 1920	
	Shock	1972 1965 1998		1972 1965 1938 1931 1894 1982 1921 2000 1998 2002 1933 1944 1887	

		(7)		(8)	
		ln(CO2 *per capita*)		**ln(CO2 *per capita*)**	
		CI term	**d(share clean)**	**CI term**	**d(share clean)**
d(lnCO_2 per capita)		-0.0079 *	-1.9729 ***	-0.0157 *	-1.9797 ***
s.d		*0.0050*	*0.2179*	*0.0089*	*0.2039*
d(ln(GDP per capita))		0.0236 ***	0.0991	0.0413 ***	-0.0162
s.d		*0.0050*	*0.2183*	*0.0097*	*0.2224*
d(% Manufacturing in GDP)		0.0013 **	-0.0065		
s.d		*0.0006*	*0.0271*		
d(SCI)				0.00236	0.075535
s.d				0.00239	0.05484
d(Openness coefficient)		-0.0044 ***	-0.0506	-0.0094 ***	-0.0389
s.d		*0.0017*	*0.0746*	*0.0034*	*0.0783*
Lags		1		1	
		1		1	
Interventions	Scale	1938 1931 2002 1934 1979 1921 1894 1958 2004 1884 1920 1983 1982 1915		1938 1931 1892 1982 1983 2004 2002 1921 1920 1958 1884 1915 2008	
	Shock	1972 1965 1959 1908 1885 1998 1916		1972 1965 1894 1959 1887 1908 1916 1885 1933 1889 1998 1899	

Finally, the *Share clean* variable is always significant for explaining the variations in carbon dioxide emissions from energy consumption (both in levels and per capita), with a negative parameter. This explains that increases in the share of clean sources of energy in the Uruguayan energy matrix substitute, at least partially, polluting sources instead of increasing the total energy supply.

6. Discussion and conclusions

This paper analyses the relationship between carbon dioxide emissions from energy consumption and per capita economic activity level in Uruguay during the period 1882–2010. This is an extraordinary time length for the analysis of a non-developed country, which allows to identify a real long-run relationship. We explore several functional forms, allowing the relationship to be logarithmic among the variables, besides the linear and quadratic models that are usually analyzed in parametric estimation in this field. We also look at the absolute and per capita terms of pollution. Empirical works often estimate the relationship only in reference to per capita emissions. These works usually look to compare results between countries, but give not a clear indication of the consequences of economic activity on the environmental pressure. This is so because while per capita emissions can be diminishing, the absolute level of emissions can continue rising due to population growth. If this happens, the pressure on the environment will not be alleviated. Other explanatory variables are included in the model for considering the productive structure, and the degree of openness of the economy. Finally, the feedback among the variables is tested through the estimation of a multi-equation model. This allows the variables to be treated as endogenous, testing if also other explanatory variables adjust to the deviations from the long-run relationship.

The results show that there exists a linear long-run relationship between carbon dioxide emissions from energy consumption and GDP per capita in Uruguay between 1882 and 2010. The existence of an inverted-U shaped curve is rejected by the estimation. Moreover, if the relationship is approached by a logarithmic path, the results are very similar to the linear model ones. In this way, if a logarithmic relationship is plausible, the degree at which the emissions per unit of GDP per capita decrease is so small that results are non-statistically different.

Second, neither absolute nor per capita emissions of Uruguay diminished with real GDP per capita growth. However, over this long period the country exhibits a very low per capita economic growth (1.3% cumulative annual growth rate). Uruguayan per capita economic activity level barely exceeded the threshold computed for France by Piaggio and Padilla (2012) only for two observations over 1882–2010. France is the developed country with a lower turning point in this study and its inverted U-shaped path is mainly explained by an increase of the nuclear energy in its energy matrix. Thus, despite the Uruguayan path is linear, this may be explained because it is still in a lower development stage than other countries that show a non-linear path.

Third, the industrialization, either measured by the industrial share on total output or by the synthetic indicator of structural change, is positively associated with carbon dioxide emissions. This is a consistent result in the literature, consequence of the composition effect. However, it is noticeable that this result emerges in a very long-run relationship, given that it was absent for the period 1950–2000 in Piaggio (2008). As was previously described, the manufacturing industry grew rapidly during the state-led industrialization model from the 1930s until the 1950s (Bértola 2008)

The industrial share recovered its levels during the 1970s and 1980s but then started a decreasing trend since the 1990s. In terms of the final energy use by sector, the industrial sector was the most important consumer during the 1940s and 1950s, representing half of the total energy consumption. This participation remained at the same level in the following decades. However, in relative terms, it presents a decreasing trend as other sectors such as transportation and residential became more energy consumer intensive (Bertoni, 2011). Both facts explain the importance of the changes in the productive structure when an extended time length is considered. Moreover, by the time the economy is more open, carbon dioxide emissions from energy consumption diminish. This is explained by the fact that the periods where the Uruguayan economy has been more open were based on primary exports (basically livestock and agricultural products) with little relevance of industrial products. The structure of exports reflect the characteristics of the manufacturing sector which has being basically composed by handicrafts, with very low installed power and labor concentration (see Willebald and Bértola (2013) for the first decades of the 20th century and Bértola and Bittencourt (2005) for the more recent period of openness).

Fourth, there exists a feedback between carbon dioxide emissions from energy consumption, per capita economic activity level and industrial share. Energy can represent a restriction to economic growth, which is reflected in this result. This means that carbon dioxide emissions from energy consumption would be a determinant factor of GDP growth. In this way, restrictions in the use of energy from fossil fuel sources could represent a threat to economic growth if it is not accompanied by efficiency improvements or replacing them for clean energy sources. The significance of the share of clean sources on total energy supply shows that changes in the energy matrix can give place to an increase in energy supply without increasing carbon dioxide emissions from energy consumption.

In summary, an increase in the economic activity level alone is not a solution for diminishing Uruguayan CO_2 emissions in the long-term. Despite the country is at a lower development stage than countries that follow a non-linear path, previous literature shows that if changes in primary energy sources are not explicitly encouraged, economic growth alone do not help to diminish emissions. The literature also shows that these policies help to achieve the turning point with a lower level of environmental pressure. Therefore, if the country expects to develop through a productive structural change where industrial sectors win participation, it should be supported by energy efficiency improvements and substitution of energy supply for clean sources. In this sense, diversification of the energy matrix by substitution for clean energies, as has been encouraged by the national government during the last years, is a smart strategy for reversing this relationship.

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Table A1: ADF Unit Root test

Null Hypothesis: the serie has a unit root		**CO$_2$**		**CO$_2$ per capita**		**ln(CO$_2$)**		**ln(CO2 per capita)**	
		Constant	**Const. + Trend**	**Constant**	**Const. + Trend**	**Constant**	**Const. + Tre**	**Constant**	**Const. + Trend**
Levels	t-stat	-0.143311	-1.975031	-0.951868	-2.003635	-2.124517	-1.221656	-1.250928	-1.779413
	p-value	0.9413	0.6092	0.7686	0.5935	0.2355	0.9013	0.6508	0.7092
	Nº lags	3	3	3	3	3	3	3	3
	RU	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1st diff.	t-stat	-4.812184	-4.804116	-9.593342	-9.553825	-10.00281	-10.25593	-10.40307	-10.38673
	p-value	0.0001	0.0008	0	0	0	0	0	0
	Nº lags	4	4	2	2	2	2	2	2
	RU	No	No	No	No	No	No	No	No

		ln(GDP per capita)		**% Manufactures in GDP**		**SCI**		**Openness coefficient**	
		Constant	**Const. + Trend**	**Constant**	**Const. + Trend**	**Constant**	**Const. + Tre**	**Constant**	**Const. + Trend**
Levels	t-stat	-1.779413	-2.708376	-1.823378	-1.963725	-1.298775	-3.242065	-1.403373	-2.556589
	p-value	0.7092	0.0753	0.3679	0.6152	0.629	0.0809	0.5789	0.3009
	Nº lags	3	0	0	0	0	0	1	1
	RU	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1st diff.	t-stat	-10.38673	-11.83745	-11.22554	-11.23091	-9.484162	-9.451661	-13.97329	-14.06543
	p-value	0	0	0	0	0	0	0	0
	Nº lags	2	0	0	0	1	1	0	0
	RU	No	No	No	No	No	No	No	No

		share_clean	
		Constant	**Const. + Trend**
Levels	t-stat	-1.388799	-1.009779
	p-value	0.5859	0.9382
	Nº lags	0	0
	RU	Yes	Yes
1st diff.	t-stat	-9.14871	-9.244286
	p-value	0	0
	Nº lags	1	1
	RU	No	No

Table A2: VECM long-run relationship quadratic model

		Extensive				**Intensive**			
		(9)	**(10)**	**(11)**	**(12)**	**(13)**	**(14)**	**(15)**	**(16)**
		CO_2	***CO_2***	***$\ln(CO_2)$***	***$\ln(CO_2)$***	***CO_2 per capita***	***CO_2 per capita***	***$\ln(CO_2$ per capita)***	***$\ln(CO_2$ per capita)***
ln(GDP per capita)		2.80E+08 ***	2.06E+08 ***	61.72 ***	88.23 ***	147.45 ***	32.34	85.39 ***	469.92 ***
s.d.		*3.69E+07*	*2.94E+07*	*19.597*	*14.239*	*20.72*	*20.89*	*16.718*	*104.162*
ln(GDP per capita)^2		2.69E+07 ***	1.96E+07 ***	5.28 ***	8.52 ***	14.32 ***	-2.65	8.31 ***	46.19 ***
s.d.		*3.34E+06*	*2659363.372*	*1.783*	*1.290*	*1.876*	*20.89*	*1.516*	*104.162*
% Manufacturing in GDP		-2.48E+06		23.84 ***		-4.44		7.60 ***	
s.d.		*1.02E+07*		*5.361*		*5.921*		*4.787*	
SCI			2.51E+06		4.78		-3.76		-10.90
s.d.			*3202599.683*		*1.648*		*2.224*		*12.099*
Openness coefficient		7.46E+06	2469878.87	-25.98 ***	-2.11	1.48	25.21 ***	-2.91	9.80
s.d.		*7.29E+06*	*5691982.993*	*3.83*	*2.841*	*4.453*	*4.266*	*3.744*	*21.737*
constant		7.23E+08	537049045	196.73	240.18	377.28	-104.90	216.59	1181.14
nº observations		128	128	128	128	128	128	128	128
Joint Akaike IC		13.62	13.62	-15.23	-13.77	-15.59	-14.84	-16.51	-14.44
Joint Schwarz criterion		17.18	17.18	-12.11	-10.76	-12.02	-9.38	-10.94	-10.43
Jarque-Bera joint normality test		10.18	15.40	24.23	187.63	18.74	22.93	20.53	38.04
p-value		*0.42*	*0.12*	*0.01*	*0.00*	*0.04*	*0.011*	*0.0246*	*0.00*
Johansen cointegration test									
Cointegrating equations at 0.05 level	Trace statistic	2	1	1	1	2	1	2	2
	Max-Eigenvalue statistic	2	1	1	2	2	1	2	2

Notes: ***,**,* significant at 1%, 5% and 10% respectively. VECM specification with linear trend in the cointegration relationship and 1 lag.

Table A3: Cointegration terms and *Share clean* coefficients in the short-run dynamics - quadratic model

Extensive					
		(9)		(10)	
		CO_2		*CO_2*	
		CI term	d(share clean)	CI term	d(share clean)
d(CO_2)		0.0064 **	-2530709.6 ***	0.0091 **	-2515051.6 ***
s.d		*0.0031*	*515582.67*	*0.0045*	*530183.52*
d(ln(GDP per capita))		-6.82E-09 ***	0.14	-8.39E-09 ***	0.1905
s.d		*0.0000*	*0.2293*	*0.0000*	*0.2402*
d(ln(GDP per capita)^2)		0.0000 ***	-1.4949	1.04E-07 ***	*-2.0387*
s.d		*0.0000*	*2.5447*	*0.0000*	*2.6658*
d(% Manufacturing in GDP)		-9.46E-11	0.0272		
s.d		*0.0000*	*0.0276*		
d(SCI)				-4.36E-10	0.1044 **
s.d				*0.0000*	*0.0571*
d(Openness coefficient)		1.86E-09 ***	-0.0381	2.48E-09 ***	-0.0635
s.d		*0.0000*	*0.0676*	*0.0000*	*0.0681*
Lags		1		1	
		1		1	
Interventions	Scale	1983 1938 1931 2002 2004 1934 1979 1960 1982 1921 1920 1885 2010		1938 1931 2002 2007 2004 1983 1934 1894 1892 1960 1982 2010 1920	
	Shock	1972 1965 2007 2000 1996 1998 1968 2006 1957 1958		1972 1965 2000 1996 1998 1958 1968 1921 2006 1957 1890	

		(11)		(12)	
		ln(CO_2)		*ln(CO_2)*	
		CI term	d(share clean)	CI term	d(share clean)
d(lnCO_2)		0.0038	-1.6581 ***	0.0046	-2.0736 ***
s.d		*0.0056*	*0.2374*	*0.0050*	*0.2430*
d(ln(GDP per capita))		1.66E-02 ***	-0.0817	-0.0198 ***	-0.2265
s.d		*0.0049*	*0.2082*	*0.0041*	*0.1986*
d(ln(GDP per capita)^2)		-0.1719 ***	0.9751	0.2451 ***	2.7151
s.d		*0.0551*	*2.3354*	*0.0453*	*2.1968*
d(% Manufacturing in GDP)		7.69E-04	0.0218		
s.d		*0.0006*	*0.0268*		
d(SCI)				-0.0008	0.1355 ***
s.d				*0.0009*	*0.0453*
d(Openness coefficient)		-1.52E-03	-0.1072 *	0.0063 ***	-0.1015
s.d		*0.0015*	*0.0647*	*0.0014*	*0.0655*
Lags		1		1	
		1		1	
Interventions	Scale	1931 2002 1979 1894 1884 1936 2006 1982 1920		1938 1931 1892 1960 2002 1934 1958 1884 1944 1890 1982 1974 1886	
	Shock	1972 1965 1938 1983 1960 2009 1958 1921 1933 1959 2009		1972 1965 1894 2009 1887	

Intensive					
		(13)		(14)	
		CO_2 *per capita*		CO_2 *per capita*	
		CI term	d(share clean)	CI term	d(share clean)
d(CO_2 per capita)		0.0036	0.9764	0.0013	-1.7214 ***
s.d		*0.0026*	*0.6944*	*0.0053*	*0.2445*
d(ln(GDP per capita))		-0.0126	0.4026	0.0145 ***	-0.1530
s.d		*0.0023*	*0.6231*	*0.0043*	*0.2010*
d(ln(GDP per capita)^2)		0.1535	-4.2169	-0.1545 ***	1.9589
s.d		*0.0255*	*6.8973*	*0.0490*	*2.2714*
d(% Manufacturing in GDP)		-0.0002	0.1518 **		
s.d		*0.0003*	*0.0837*		
d(SCI)				0.0013 *	0.0677
s.d				*0.0013*	*0.0611*
d(Openness coefficient)		0.0029	-0.0201	-0.0052 ***	0.0277
s.d		*0.0007*	*0.1941*	*0.0015*	*0.0679*
Lags		1		1	
		1		1	
Interventions	Scale	1938 1931 1983 1960 1979 2002 1934 1921 2008 1920 2004 1982 2006 1991 1959		1892 2008 2004 1960 1982 1958 1920 1974 2006 1979 1936 1948 1991 1988	
	Shock	1972 1965 1998 2009 1957 1885 1974 2000		1972 1965 1938 1931 1894 1982 1921 2000 1998 2002 1933 1944 1887 2009 1951 1918 1985 1941 1885 1889 1967 1905 1916 1908	

		(15)		(16)	
		ln(CO_2 *per capita*)		ln(CO_2 *per capita*)	
		CI term	d(share clean)	CI term	d(share clean)
d(lnCO_2 per capita)		0.0049 **	-1.7740 ***	0.0009 *	-2.0897 ***
s.d		*0.0028*	*0.1753*	*0.0006*	*0.2079*
d(ln(GDP per capita))		-0.0162 ***	0.4685 **	-0.0024 ***	0.1559
s.d		*0.0035*	*0.2162*	*0.0006*	*0.2104*
d(ln(GDP per capita)^2)		0.1984 ***	-4.9135 **	0.0302 ***	-1.4227
s.d		*0.0386*	*2.4074*	*0.0066*	*2.3252*
d(% Manufacturing in GDP)		0.0002	-0.0500 **		
s.d		*0.0005*	*0.0283*		
d(SCI)				-6E-06	0.080607
s.d				*0.0002*	*0.0555*
d(Openness coefficient)		0.0025 **	-0.0754	0.0006 ***	-0.0934
s.d		*0.0013*	*0.0804*	*0.0002*	*0.0726*
Lags		1		1	
		1		1	
Interventions	Scale	1938 1931 1892 1982 1983 2004 2002 1921 1920 1958 1884 19152008 1979 1974 1931 1932 2006 1922 1942 1953 1912		1938 1931 1892 1982 1983 2004 2002 1921 1920 1958 1884 1915 2008 1974	
	Shock	1972 1965 1894 1959 1887 1908 1916 1885 1933 1889 1998 1899 2009 1968 1895 1897 2000 1951 1910		1972 1965 1894 1959 1887 1908 1916 1885 1933 1889 1998 1899 2009	

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