Décimas Jornadas de Investigación en Historia Económica

Asociación Uruguaya de Historia Económica,10-11 de Julio de 2014, Montevideo.

The long-run relationship between CO_2 emissions and economic activity in a small open economy: Uruguay 1879 - 2010[1]

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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 1879 and 2010. We apply cointegration techniques and estimated 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 share of industry in total output, the degree of openness, and the contract enforcement as a signal of the institutional framework 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 importance 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 institutional framework only explains the variations in the degree of openness. Finally, carbon dioxide emissions, economic activity level and the share of industry in total output are endogenous, adjusting together to the deviations from the long-run relationship. The degree of openness is weakly exogenous as a consequence of the importance of external (exogenous) factors on its behavior, e.g. international prices. 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

[1] We thanks the suggestions made by Henry Willebald.

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, 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 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 tendency (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 non-polluting activities (like primary 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).

The role of institutional aspects are also important for explaining countries' environmental performance. Institutions have a relevant role in the functioning of both economies and politics, and so in the impact of humans on the environment. It is expected that higher quality in reference to the institutional framework would have a positive impact on environmental regulation. Different institutional aspects have been introduced in the EKC literature, such as environmental regulation and international agreements (de Bruyn, 1997), political variables (Panayoutou, 1997), the distribution of power (Torras and Boyce, 1998), political rights and civil liberties (Bhattarai and Hammig, 2001), and the level of corruption (Leitão, 2010). There are many ways to interpret how formal and informal institutions affect economic and environmental issues but, above all, there is a strong difficulty in how to measure the relevant aspects of existing institutions in order to use them as synthetic variables in statistical analysis.

Empirical studies on the EKC often only analyze 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 emissions absolute value is considered.[2] A similar concept has been used in the literature for the distinction between relative and absolute decoupling (or weak and strong delinking) (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.

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 benefits 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).

[2] 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.

Most of the studies estimate a long-run relationship between environmental degradation or energy use and economic level activity with short time periods, because of data constraints (60 years of shorter). 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) 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 1879–2010. 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 products. The Uruguayan case has been previously studied by Piaggio (2008) for a much shorter period (1950–2000) and a descriptive analysis of the EKC for the long-run can be found in Bertoni and Román (2006). The present study not only update 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 factor 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 also 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 productive structural change 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, the share of the industrial sector in the Uruguayan economy and its degree of openness are considered in the analysis. In addition, during the last 130 years the country experienced diverse socio-political and economic scenarios. Therefore, the evolution of institutional aspects is considered in the study by means of an indicator of the changes in the contractual enforcement. The historical context and an overview of the evolution of these variables are more extensively discussed in the next section.

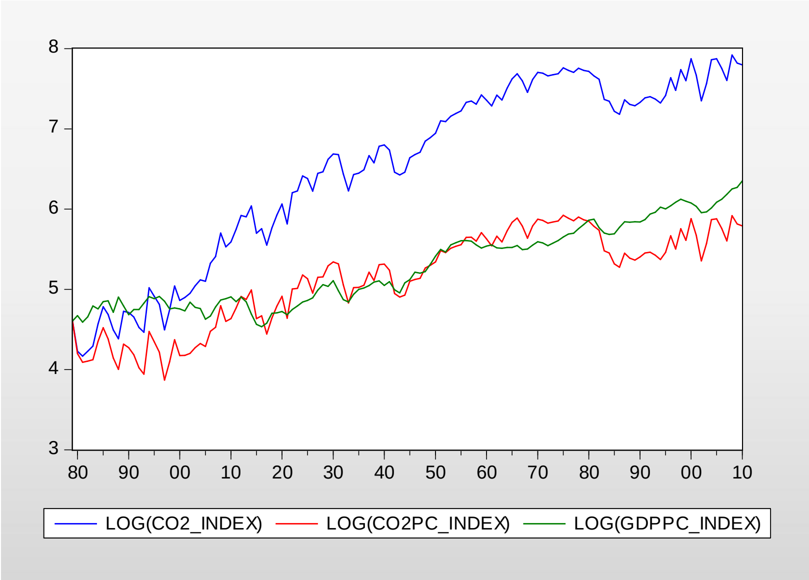
The rest of the paper is organized as follows: Section 2 narrates the evolution of the variables of interest in Uruguay during the last 130 years. Section 3 explains the model specification and the empirical strategy. Data is described in Section 4, and Section 5 presents the results. Finally, Section 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 1879–2010) and showed a very unstable performance (Figure 1). 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, 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, carbon dioxide emissions per capita and GDP per capita (logarithms, index 1879=100)



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

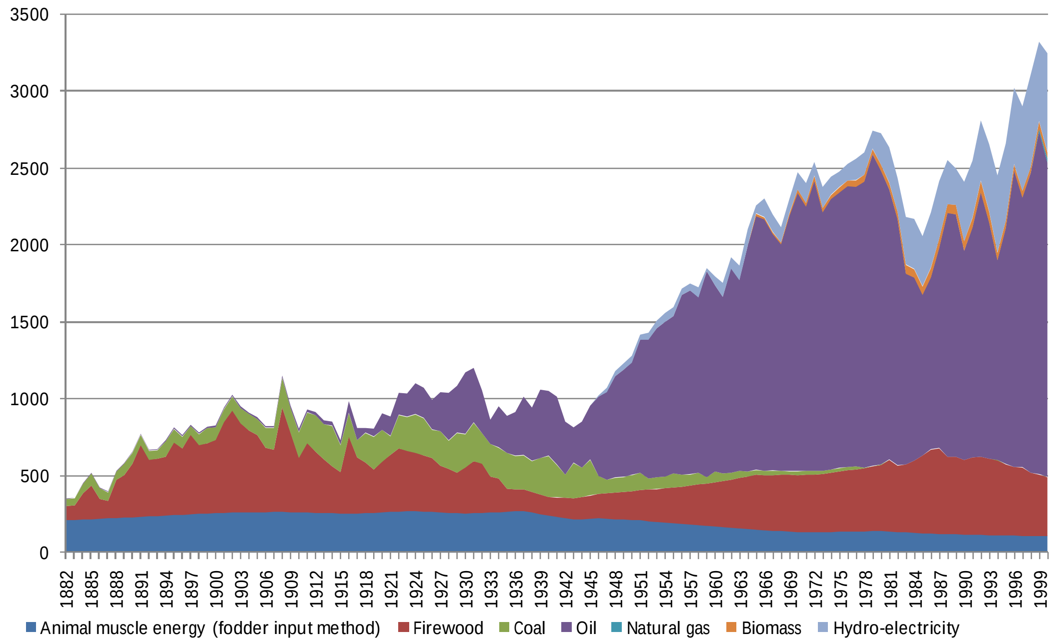
These divergent trajectories may also be explained by the changes of the Uruguayan productive structure over the last century. Economic history identifies three phases of development patterns (Bértola y Porcile, 2000; Bértola, 2008; Bonino et al. 2012). Uruguay implemented outward-oriented trade strategies during the periods of globalization, and the import substitution industrialization police was the model adopted between the 1930s and the 1970s (Bertino et al 2001). During the first globalization, from the last decades of the 19th century to the 1930s, growth was led by exports, based on a few primary products, and the country achieved high income levels in comparative terms (Finch 1980). The agrarian activities represented less than one third of the total economy between 1870 and 1930 while the share of the industrial sector was around 15% of GDP (Figure 2) (Bonino et al. 2012). As a consequence of the 1929 Crisis and the Great Depression, together with most of the Latin American countries, the country adopted inward-oriented policies and the Import Substitution Industrialization (ISI) or State-led Industrialization as a strategy to promote growth (Bulmer Thomas 1998, Bértola and Ocampo 2010). The industrial sector increased its importance in economic activity, representing little less than one third of total GDP, contrary to what happened to the agriculture that followed a declining participation. 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 (Arnábal et al. 2013, 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 maintain 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 even identify this process with a deindustrialization period (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 1980s and 2000s, respectively.

Figure 2: Uruguayan productive structure: value added by activity (% of total value added)

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 of the prices of commodities (Bulmer Thomas 1998, Bértola and Ocampo 2010). 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. 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 is still far away from oil.

Figure 3: Uruguay energy consumption composition (ktoe). 1882-2000.



Source: own elaboration based on Bertoni (2011)

From the above we may say that the dynamic transformations 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 have also been periods of important agricultural exports in response to the international prices dynamics. As a consequence, the degree of openness is expected to be inversely related with carbon dioxide emissions, other things equal.

At the same time, changes in the institutional framework affect economic activity. In order to evaluate the role of some institutional aspects, we use an indirect measure of contract enforcement, the contract-intensive money (CIM). This indicator was proposed by Clague et al. (1999) who argue that the relative use of currency in comparison with contract-intensive money can bring an idea of the extent to which societies rely on contract enforcement and property rights.[3] As any other measure, this one cannot prevent from presenting some drawbacks. The most important is that, at least in some periods, the evolution of the CIM may be explained by changes in the financial system due to factors not related to the enforcement of contracts but

[3] In future stages we will discuss other indicators and measures of the institutional quality.

with the general macroeconomic context (Clague et al. 1999). Nevertheless, the historical evolution of this indicator coincides with the three phases of Uruguayan development described below (Fleitas et al., 2013). From the economic point of view, the greater this variable the more encouragement would be to transactions and investments. The impact of this variable on the environment is less obvious but we may expect that a society, in which the transparency of property rights and contractual enforcement improves, would also be associated to stronger institutions to enforce rules and regulations (including environmental ones). For the case of CO_2, as a global pollutant, the impact may be less clear than for other types of environmental degradations, but it may be taken into account that CO_2 emissions are usually associated to other environmental pressures that may be more closely affected by existing rules and regulations at national level.[4]

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

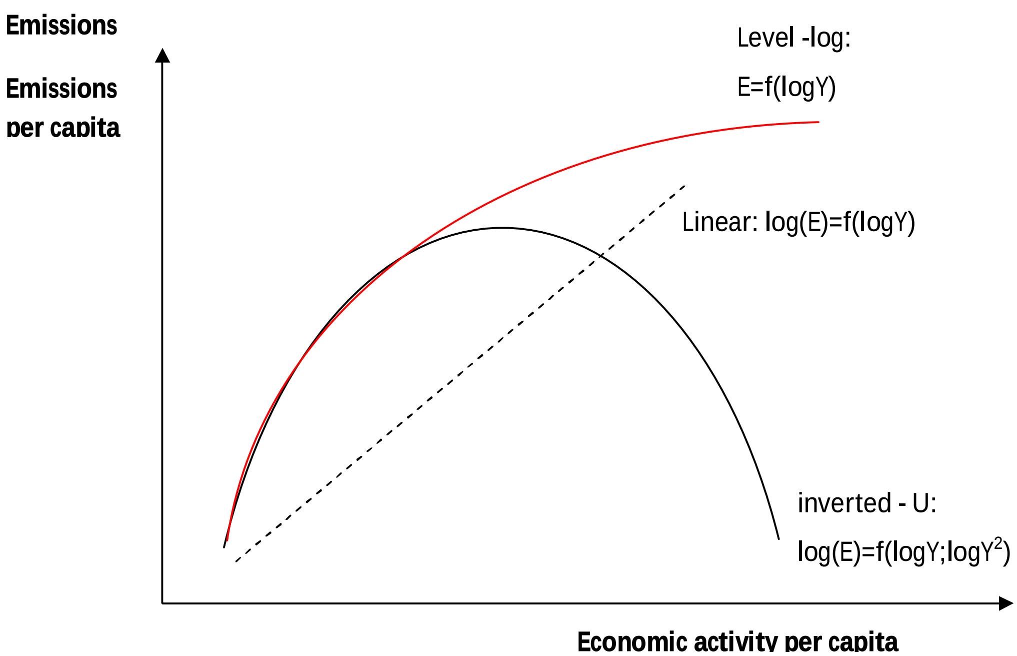
E_t denotes carbon dioxide emissions, Y_t is income per capita in period $t=1, ...T$, and ε_t is the error term normally distributed. The correct functional form for each country can be specified from the equation above. An inverted-U relationship is denoted by $\beta_1>0$, $\beta_2<0$.

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 fact, because this relationship can follow different paths that would be omitted when automatically employing this transformation. For our interest, 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

[4] We recognize that this is a limited aspect of institutional performance and, in general of the influence of institutions on the environment, so, in future research we will try to complement it with other relevant institutional indicators such as distribution of power and quality of democracy, among others (Siniscalchi 2014) .

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 of emissions per unit of output is not constant. This would be better reflected by a level - log functional form (as depicted by the red 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 β% change in E), in the level - log specification a 1% change in Y means a β units change in E.

Figure 4: Functional forms



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 the share of the industrial sectors in economic activity. 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). Third, we also include a variable for considering institutional aspects referring to market transparency and contracts enforcement. The technological effect is captured allowing a linear trend in the data.

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, energy policies 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 y 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; Vona, 2012; Borozan, 2013). Stern and Enflo (2013) employ several of the techniques at the same time.

In this paper we employ the last strategy, estimating a VECM (Banerjee et al., 1993). A VECM 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 et al. 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:

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

where $\varepsilon_i \sim N(0, \sigma^2)$, 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.[5]

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

The time series covers the period 1879–2010 as the available energy data starts in 1879. 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, 1879–1955 they are estimations, and therefore present the expected limitations of the historical reconstructions of macro variables. In particular, the nineteenth century is the weaker period especially due to the lack of information. 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 by Banco de la República (1965) and afterwards by Banco Central del Uruguay in several publications and data available online.[6] 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 figures of population 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*

[5] When a quadratic transformation of the economic activity level is included, the behavior of the residuals on their equation is ignored. 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.

[6] http://www.bcu.gub.uy/

Social.[7] The industrial share in the economic activity is calculated as the participation of the value added of the industrial sector in the 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 gross domestic product. The openness coefficient is the ratio of exports plus imports to gross domestic product (all variables in Uruguayan pesos at current prices). The series were estimated by Román (2013) based on several sources. Since 1955, the exports and imports of goods and services were obtained from the SNA. For the pre-national accounts period, the information available is restricted to good trade and was obtained from Bonino et al. 2013, Finch (1980) and Acevedo (1933, 1934).

In the case of the Uruguayan economy, carbon dioxide emissions (CO_2) are the resulted of 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 is 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 for energy consumption starts in 1965 with the elaboration of the national energy balance by the *Dirección Nacional de Energía* which brings indicators of the gross energy supply by primary sources.[8] 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 estimation of the apparent consumption of energy for the earlier decades (1879–1937).

Finally, in order to evaluate the role of institutional arrangements, we use the contract-intensive money (CIM) which, following Clague et al. (1999), is defined as the ratio of non-currency money to total money supply. For Uruguay long series of currency in circulation and deposits, needed to calculate the CIM, were estimated by Román and Willebald (2011) and used in Fleitas et al. (2013). The main information from 1912 onwards was taken from Banco Central del Uruguay (1971; and data on-line). For the previous period the series were estimated by Román and Willebald (2011) on the basis of several sources.

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 except the *CIM* variable (Table A1 in the Appendix). Therefore, the vector of endogenous variables in Eq. (4) is defined by $X_t = \{E_t, ln(GDP\ per\ capita)_t, \%\ Industries\ in\ GDP_t, Open\ _t\}$, while *CIM* is considered as exogenous, only related with the first difference of the endogenous variables. A quadratic

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

transformation of the 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. (4) 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:

$$(5)\ \begin{Bmatrix} \Delta E_t \\ \Delta ln(GDP\ per\ capita)_t \\ \Delta\%\ Industries\ in\ GDP_t \\ \Delta Open\ _t \end{Bmatrix} = A_1 \begin{Bmatrix} \Delta E_{t-1} \\ \Delta ln(GDP\ per\ capita)_{t-1} \\ \Delta\%\ Industries\ in\ GDP_{t-1} \\ \Delta Open\ _{t-1} \end{Bmatrix} + \Pi \begin{Bmatrix} E_t \\ ln(GDP\ per\ capita)_t \\ \%\ Industries\ in\ GDP_t \\ Open\ _t \end{Bmatrix} + \mu + \Gamma_1 CIM_t + \Gamma_2 d_t + \varepsilon_t$$

Table A2 in the Appendix shows the results for the long-run relationship. The main results are summarized in Table 1. A linear relationship between carbon dioxide emissions and economic activity is found for per capita and absolute terms. In addition, an increase in the share of the industrial sector in total GDP is positively correlated with carbon dioxide emissions, consequence of the increase in energy consumption by these sectors.[9] This result is in line with Shen (2006) in 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). This variable was not significant in Piaggio (2008) for the period 1950–2000. 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 exports. These are low intensive 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

[9] Despite in model (20) the share of the industrial sector in total GDP is not significant, it turns into significant if the confidence level of the test is increased until 12%.

reference to sulfur dioxide emissions in a panel of 42 and 94 countries respectively. The opposite result was estimated by Haciloglu (2009) in 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	
		(4)	(12)	(20)	(28)
		CO_2	*ln(CO2)*	*CO2 per captia*	*ln(CO2 per capita)*
ln(GDP per capita)		-9.67E+09 *	-4.94E+00 *	-2.75E+06 *	-2.80E+00 *
s.d.		*1.44E+09*	*7.94E-01*	*4.47E+05*	*4.56E-01*
% Industries in GDP		-1.86E+10 **	-1.11E+01 ***	-4.84E+06	-6.04E+00 ***
s.d.		*7.26E+09*	*4.08E+00*	*2.27E+06*	*2.33E+00*
Open coefficient		1.41E+10 *	1.04E+01 *	5.40E+06 *	5.88E+00 *
s.d.		*5.15E+09*	*2.87E+00*	*1.60E+06*	*1.65E+00*
cte.		7.65E+10	1.85E+01	2.09E+07	8.74E+00
Joint Akaike IC		30.65	-12.25	15.32	-12.24
Joint Schwarz criterion		33.45	-9.87	17.94	-9.86
Jarque-Bera joint normality test		16.85	18.39	19.33	19.19
p-value		*0.03*	*0.02*	*0.01*	*0.01*
Johansen cointegration test					
Cointegrating equations at 0.05 level	Trace statistic	1	1	1	1
	Max-Eigenvalue statistic	1	1	1	1

Notes: *, **, *** significant at 1%, 5% and 10% respectively. VECM specification with linear trend in the cointegration relationship and 1 la
Coefficients from the cointegration relationship must be interpreted with the opposite sign

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 $ln(GDP\ per\ capita)$. After that, the Box-Cox statistic to test the null hypothesis that both models are equal is conducted (Table 2).[10] The result shows that working with the logarithm transformation of the carbon dioxide emissions for modeling its relationship with the level 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.

[10] 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 adjusted computing its geometric mean (CO_2_adj). After that, the Box-Cox statistic is computed (BoxCox = 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).

Table 2: Uni-equation models

	CO2_adj	*ln(CO2_adj)*	*CO2 per captia_adj*	*ln(CO2 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*
cte.	-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.				

When looking at the quadratic term of the economic activity level, it is not significant or depicts a U-shaped relationship (Table A2 in the Appendix). This is consequence of the very irregular path of the series included for Uruguay, where many economic crises took place during the 130 years. In this way, an inverted U-shaped functional form is also discarded. 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 if well 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. Moreover, given that the quadratic transformation of GDP per capita was not significant (or gave weak results), this is not a big issue.

Table 3 shows the cointegration term (α_i) and the coefficient associated to the *CIM* variables from Eq. (5) for those models (4), (12), (20) and (28) shown in Table A2 in the Appendix. 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 series are endogenous except the degree of openness, that is weakly exogenous. This means that expect *Open*, all the other 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 and the industrial share in GDP, but it also explains them. The fact that the degree of openness is weak exogenous can be explained because Uruguay is a very small country, where external shocks are usually taken as exogenous. The same reasoning can be explaining this result, because Uruguayan trade is mainly driven by international prices, which are exogenous to the country.

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

Extensive margin (absolute emissions)					
Level - Log - Model (4)					
		d(CO_2)	d(ln(GDP per capita))	d(% Industries in GDP)	d(Open coefficient)
CI coefficient		-0.017226089 ***	1.32E-11 *	1.24E-12 *	-1.15E-12
s.d		*1.01E-02*	*3.73E-12*	*4.31E-13*	*1.14E-12*
CIM		-5.29E+08	0.166233473	2.04E-02	-8.75E-02 **
s.d.		*3.87E+08*	*1.43E-01*	*1.65E-02*	*4.37E-02*
Lags		1	1	1	1
Interventions	Scale	2002, 1983, 1931, 2004, 1958, 1934, 1891, 1885, 1898, 1960, 1979, 1920			
	Shock	2007, 1972, 1938, 1965, 1996, 1998, 2000, 1887, 1911, 1906, 1909, 1921			
RSS adj		2.764	1.229	0.015	0.112

Extensive margin (absolute emissions)					
Log - Log - Model (12)					
		d(ln(CO_2))	d(ln(GDP per capita))	d(% Industries in GDP)	d(Open coefficient)
CI coefficient		-0.015 ***	0.026 *	0.002 *	-0.003
s.d		*8.73E-03*	*6.83E-03*	*8.42E-04*	*2.03E-03*
CIM		-1.33E-01	0.081296482	2.16E-02	-9.03E-02 **
s.d.		*1.85E-01*	*1.45E-01*	*1.78E-02*	*4.30E-02*
Lags		1	1	1	1
Interventions	Scale	1931, 2002, 1983, 1934, 1891, 1885, 1898, 1979, 2004, 1960, 1958, 1894			
	Shock	1972, 1965, 1938, 1887, 1911, 1906, 1921			
Note: *, **, *** significant at 1%, 5% and 10% respectively.					

Tables 3: Cointegration terms and *CIM* coefficients in the short-run dynamics (cont.)

Intensive margin (per capita emissions)					
Level - Log - Model (20)					
		d(CO_2 per capita)	d(ln(GDP per capita))	d(% Industries in GDP)	d(Open coefficient)
CI coefficient		-0.032 **	4.29E-08 *	4.23E-09 *	-4.74E-09
s.d		*1.59E-02*	*1.22E-08*	*1.47E-09*	*3.63E-09*
CIM		-1.80E+05	0.152583824	2.32E-02	-8.38E-02 **
s.d.		*1.84E+05*	*1.42E-01*	*1.71E-02*	*4.21E-02*
Lags		1	1	1	1
Interventions	Scale	2004, 1983, 1879, 1931, 1934, 1891, 1885,1898, 1979, 1920, 2003, 1960, 1958			
	Shock	2007, 1972, 1938, 1965, 1887, 1911, 1906, 1921			

Intensive margin (per capita emissions)					
Log - Log - Model (28)					
		d(ln(CO_2 per capita))	d(ln(GDP per capita))	d(% Industries in GDP)	d(Open coefficient)
CI coefficient		-0.030 **	0.043 *	0.004 *	-0.005
s.d		*1.53E-02*	*1.21E-02*	*1.48E-03*	*3.57E-03*
CIM		-1.48E-01	1.03E-01	0.023542	-0.092821 **
s.d.		*-1.85E-01*	*-1.46E-01*	*-1.78E-02*	*-4.30E-02*
Lags		1	1	1	1
Interventions	Scale	1931, 2002, 1983, 1934 ,1891, 1885, 1898 ,1979, 2004, 1960, 1958 ,1894			
	Shock	1972, 1938, 1965,1931,1887 ,1911, 1906, 1921			
Note: *, **, *** significant at 1%, 5% and 10% respectively.					

Finally, the *CIM* variable is only significant for explaining the variations in the grade of openness, with a negative parameter. This means that the Uruguayan degree of openness increases at a lower rate when the institutional framework is stronger. The *CIM* gives information about transparency in property rights and contracts enforcing for encouraging investment. Uruguayan main openness is explained by primary products exports, which do not necessarily require contexts where the institutional level is strong, and do not need a strong investment climate. Moreover, the growth rate of the other endogenous variables is not significantly affected by the *CIM* variable. This means that a better investment climate in the country does not have impact on the rate of carbon dioxide emissions, economic activity level, or industrial share.

6. Discussion and conclusions

The present paper analyses the relationship between carbon dioxide emissions from energy consumption and per capita economic activity level in Uruguay during the period 1879–2010. 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 terms 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 are not useful for mitigating the environmental impact of emissions. This is because while per capita emissions can be diminishing, the absolute level of emissions can continue growing. If this happens, the impact on the environment will not be alleviated. Other explanatory variables are included in the model for considering the productive structure, the degree of openness of the economy, and the transparency and contract enforcement given by the institutional framework. 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 1879 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 exhibit a very low per capita economic growth (13% annual accumulate growth). Uruguayan per capita economic activity level barely exceeded the threshold computed for France by Piaggio and Padilla (2012) only for two observations over 1879-2010. France is the developed country with a lower turning point in this study which inverted U-shaped path is mainly explained by an increase of the nuclear energy in its energy matrix. Thus, despite Uruguayan path is linear, this can be explained because it is still in a lower development stage than other countries that show a non-linear path.

Third, the share of the industrial sector in the GDP 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 described, the manufacturing industry showed a very dynamic performance during the state-led industrialization between the 1930s and earlier 1950s (Bértola 1991, Arnábal et al. 2013) when it faced a decade of stagnation. 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 activities were the most important consumer in the 1940s, 1950s, representing half of the total energy consumption but showed a stable participation 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 explains the importance of the productive structure when the time length is extended. Similar interpretations were introduced by Bertoni and Román (2006) in their analysis.

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 in primary and agro-based exports (basically livestock and agricultural products) with very low industrial content. 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). Contract enforcement, which reflect one important dimension of the institutional quality institutions, only impact on the variations of the degree of openness. Environmental problems are a relative modern fact in political agenda, which emerged since the Stockholm 1972 conference. Because of this, we find reasonable that there does not exist a long-run correlation between the institutional framework and the environmental aspect considered; specially taking into account that no measures were taken as regards CO_2 emissions in almost any country until the 2000s. However, this has been a very important fact in relationship to foreign investment and opening international markets for agro-based products like the once that dominates Uruguayan exports.

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 that is reflected in this result. This means that carbon dioxide emissions from energy consumption would be a determinant factor of the 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 made together with efficiency improvements or clean sources energy substitution. The degree of openness of the economy is the only weakly exogenous variable of those included in the cointegration vector. This is a reasonable result, given that Uruguay is a very small open economy whose exports depend mainly on exogenous factors, like market access and international prices, more than on local endogenous variables.

In summary, increases in the economic activity level alone is not a solution for diminishing Uruguayan CO_2 emissions in the long-term. Despite the country is in a lower development stage than countries that follow a non-linear path, previous literature show that if changes in primary energy sources are not explicitly encouraged, economic growth alone do not help to diminish environmental pressure from emissions. 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 by 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 delinking this relationship.

Moreover, other factors not considered in this version of the paper can be driving the long-run relationship between carbon dioxide emissions and per capita economic activity level. Further steps would be to better explain the changes in the productive structure, the industrial composition and the uses of energy by activities, and include other institutional dimensions, like inequality and power asymmetries, as well as demographic and climatic variables.

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Table A1: ADF Unit Root test

Null Hypothesis: the serie has a unit root		CIM		CO_2		CO_2PC		LNCO_2	
		Cte.	Cte. + Tend	Cte.	Cte. + Tend	Cte.	Cte. + Tend	Cte.	Cte. + Tend
Levels	t-stat	-3.589153	-3.570749	-0.143311	-1.975031	-1.485525	-2.215716	-2.124517	-1.221656
	p-value	0.0072	0.0363	0.9413	0.6092	0.538	0.4766	0.2355	0.9013
	Nº lags	1	1	3	3	3	3	3	3
	RU	No	No	Si	Si	Si	Si	Si	Si
1st diff.	t-stat	-6.033915	-6.01082	-4.812184	-4.804116	-9.674124	-9.664513	-10.00281	-10.25593
	p-value	0	0	0.0001	0.0008	0	0	0	0
	Nº lags	4	4	4	4	2	2	2	2
	RU	No	No	No	No	No	No	No	No

		LNCO_2PC		GDP_DOLLARSCTE		GDPPC_DOLLARSCTE		LNGDPPC_DOLLARSCTE	
		Cte.	Cte. + Tend	Cte.	Cte. + Tend	Cte.	Cte. + Tend	Cte.	Cte. + Tend
Levels	t-stat	-1.250928	-1.779413	-0.452898	-3.615043	-1.930472	-3.35638	-2.706907	-3.433179
	p-value	0.6508	0.7092	0.8954	0.0323	0.3175	0.0619	0.0755	0.0514
	Nº lags	3	3	1	2	1	2	0	0
	RU	Si	Si	Si	No	Si	Si	Si	Si
1st diff.	t-stat	-10.40307	-10.38673	-8.44933	-8.523293	-9.387428	-9.436573	-11.96622	-11.96218
	p-value	0	0	0	0	0	0	0	0
	Nº lags	2	2	0	0	0	0	0	0
	RU	No	No	No	No	No	No	No	No

		LNGDP_DOLLARSCTE		OPEN		SHARE_IND	
		Cte.	Cte. + Tend	Cte.	Cte. + Tend	Cte.	Cte. + Tend
Levels	t-stat	-1.360384	-4.363959	-1.666874	-2.265099	-1.933308	-2.535347
	p-value	0.5998	0.0035	0.4457	0.4496	0.3162	0.3109
	Nº lags	0	0	1	1	1	1
	RU	Si	No	Si	Si	Si	Si
1st diff.	t-stat	-11.97505	-11.92688	-13.77054	-13.80365	-13.84888	-13.81218
	p-value	0	0	0	0	0	0
	Nº lags	0	0	0	0	0	0
	RU	No	No	No	No	No	No

Table A2: VECM long-run relationship

	Extensive							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2
ln(GDP per capita)	-8.41E+09 *	-6.16E+09 *	-2.36E+10 *	-9.67E+09 *	2.10E+12 *	-6.84E+10	3.45E+11 **	-1.98E+11
s.d.	*1.95E+09*	*1.04E+09*	*-5.00E+09*	*1.44E+09*	*5.29E+11*	*5.73E+10*	*7.66E+10*	*9.61E+10*
ln(GDP per capita)^2					-1.22E+11 *	3.37E+09	-2.07E+10 **	1.07E+10
s.d.					*3.17E+10*	*3.43E+09*	*4.59E+09*	*5.76E+09*
% Industries in GDP		-1.53E+10 **		-1.86E+10 ***		-1.99E+10		-1.97E+10
s.d.		*5.66E+09*		*7.26E+09*		*9.84E+09*		*1.64E+10*
Open coefficient			6.93E+10 *	1.41E+10 *			3.00E+10	3.31E+09
s.d.			*-1.80E+10*	*5.15E+09*			*9.43E+09*	*1.18E+10*
cte.	6.70E+10	5.12E+10	1.71E+11	7.65E+10	-9.04E+12	3.36E+11	-1.45E+12	9.05E+11
Joint Akaike IC	40.59	34.55	36.55	30.65	38.78	32.46	34.73	28.25
Joint Schwarz criterion	41.42	36.65	37.86	33.45	40.09	35.34	36.56	32.18
Jarque-Bera joint normality test	9.57	10.56	12.80	16.85	426.43	268.22	355.09	240.37
p-value	*0.05*	*0.10*	*0.05*	*0.03*	*0.00*	*0.00*	*0.00*	*0.00*
Johansen cointegration test								
Cointegrating equations at 0.05 level — Trace statistic	1	1	0	1	1	2	2	2
Cointegrating equations at 0.05 level — Max-Eigenvalue statistic	1	1	1	1	1	2	2	2

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

Normality test of the residuals in the models with a quadratic transformation of the economic activity level is reached for all the equations except for the one that refers to this variables. Because of this the joint normality test is not significant, but inference is valid for the equations of interest.

Coefficients from the cointegration relationship must be interpreted with the opposite sign

Table A2: VECM long-run relationship (cont.)

		Extensive							
		(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
		ln(CO2)	*ln(CO2)*	*ln(CO2)*	*ln(CO2)*	*ln(CO2)*	*ln(CO2)*	*ln(CO2)*	*ln(CO2)*
ln(GDP per capita)		-4.19E+00 *	-3.69E+00 *	-7.57E+00 *	-4.94E+00 *	1.21E+03 **	-1.37E+02 **	9.68E+01	5.49E+01
s.d.		*1.24E+00*	*7.63E-01*	*1.72E+00*	*7.94E-01*	*3.97E+02*	*5.41E+01*	*4.91E+01*	*1.56E+01*
ln(GDP per capita)^2						-7.04E+01 **	7.53E+00 ***	-6.22E+00	-3.45E+00
s.d.						*2.38E+01*	*3.24E+00*	*2.94E+00*	*9.35E-01*
% Industries in GDP			-9.70E+00		-1.11E+01 ***				-1.21E+01
s.d.			*4.28E+00*		*4.08E+00*				*2.80E+00*
Open coefficient				2.21E+01 *	1.04E+01 *		-1.60E+01	2.72E+01 **	9.64E+00
s.d.				*6.22E+00*	*2.87E+00*		*9.65E+00*	*6.05E+00*	*1.95E+00*
cte.		1.35E+01	1.12E+01	3.45E+01	1.85E+01	-5.23E+03	5.95E+02	-4.04E+02	-2.39E+02
Joint Akaike IC		-2.13	-8.12	-6.25	-12.25	-3.54	-10.21		-13.88
Joint Schwarz criterion		-1.51	-6.47	-5.12	-9.87	-2.81	-7.83		-10.90
Jarque-Bera joint normality test		6.87	11.49	13.20	18.39	236.15	256.74	133.77	267.66
p-value		*0.14*	*0.07*	*0.04*	*0.02*	*0.00*	*0.00*	*0.00*	*0.00*
Johansen cointegration test									
Cointegrating equations at 0.05 level	Trace statistic	0	1	0	1	1	1	1	1
	Max-Eigenvalue statistic	1	1	1	1	0	1	1	1

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

Normality test of the residuals in the models with a quadratic transformation of the economic activity level is reached for all the equations except for the one that refers to this variables. Because of this the joint normality test is not significant, but inference is valid for the equations of interest.
Coefficients from the cointegration relationship must be interpreted with the opposite sign

Table A2: VECM long-run relationship (cont.)

		Intensive							
		(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
		CO2 per captia	*CO2 per captia*	*CO2 per captia*	*CO2 per captia*	*CO2 per captia*	*CO2 per captia*	*CO2 per captia*	*CO2 per captia*
ln(GDP per capita)		-1.96E+06 *	-1.84E+06 *	-4.99E+06 *	-2.75E+06 *	2.75E+08 *	-3.99E+07	9.59E+07 *	1.04E+15 **
s.d.		*5.46E+05*	*3.53E+05*	*1.12E+06*	*4.47E+05*	*6.38E+07*	*2.30E+07*	*2.12E+07*	*2.68E+15*
ln(GDP per capita)^2						-1.60E+07 *	2.13E+06	-5.75E+06 *	-6.04E+15 **
s.d.						*3.82E+06*	*1.38E+06*	*1.27E+06*	*1.61E+15*
% Industries in GDP			-4.46E+06 ***		-4.84E+06		-5.62E+06		-4.39E+15
s.d.			*1.96E+06*		*2.27E+06*		*4.01E+06*		*4.65E+15*
Open coefficient				1.48E+07 *	5.40E+06 *			9.14E+06 ***	7.41E+15
s.d.				*4.00E+06*	*1.60E+06*			*2.62E+06*	*3.30E+15*
cte.		1.52E+07	1.50E+07	3.56E+07	2.09E+07	-1.18E+09	1.84E+08	-4.03E+08	-4.45E+15
Joint Akaike IC		25.32	19.40	21.10	15.32	23.60	17.21	19.41	13.40
Joint Schwarz criterion		26.06	21.24	22.42	17.94	24.65	19.83	21.07	16.67
Jarque-Bera joint normality test		10.22	10.20	5.69	19.33	366.45	246.40	297.44	148.61
p-value		*0.04*	*0.12*	*0.46*	*0.01*	*0.00*	*0.00*	*0.00*	*0.00*
Johansen cointegration test									
Cointegrating equations at 0.05 level	Trace statistic	1	1	0	1	1	1	1	2
	Max-Eigenvalue statistic	1	1	1	1	1	1	2	2

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

Normality test of the residuals in the models with a quadratic transformation of the economic activity level is reached for all the equations except for the one that refers to this variables. Because of this the joint normality test is not significant, but inference is valid for the equations of interest.

Coefficients from the cointegration relationship must be interpreted with the opposite sign

Table A2: VECM long-run relationship (cont.)

	Intensive							
	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)
	ln(CO2 per capita)	*ln(CO2 per capita)*	*ln(CO2 per capita)*	*ln(CO2 per capita)*	*ln(CO2 per capita)*	*ln(CO2 per capita)*	*ln(CO2 per capita)*	*ln(CO2 per capita)*
ln(GDP per capita)	-2.46E+00 *	-2.04E+00 *	-5.20E+00 *	-2.80E+00 *	3.50E+02 *	-2.95E+01	5.66E+01	1.09E+01
s.d.	*7.76E-01*	*4.28E-01*	*1.20E+00*	*4.56E-01*	*1.12E+02*	*2.03E+01*	*2.47E+01*	*1.08E+01*
ln(GDP per capita)^2					-2.03E+01 *	1.54E+00	-3.58E+00 ***	-7.96E-01
s.d.					*6.68E+00*	*1.22E+00*	*1.48E+00*	*6.50E-01*
% Industries in GDP		-5.26E+00		-6.04E+00 ***		-5.17E+00		-6.15E+00
s.d.		*2.39E+00*		*2.33E+00*		*3.59E+00*		*1.92E+00*
Open coefficient			1.64E+01 *	5.88E+00 *			1.47E+01 *	4.86E+00 *
s.d.			*4.29E+00*	*1.65E+00*			*3.09E+00*	*1.36E+00*
cte.	6.58E+00	4.14E+00	2.42E+01	8.74E+00	-1.52E+03	1.25E+02	-2.41E+02	-5.01E+01
Joint Akaike IC	-2.07	-8.11	-6.22	-12.24	-3.55	-10.05	-7.76	-14.12
Joint Schwarz criterion	-1.50	-6.46	-5.16	-9.86	-2.82	-7.76	-6.44	-11.03
Jarque-Bera joint normality test	10.20	11.86	14.64	19.19	240.92	290.43	140.40	297.04
p-value	*0.04*	*0.07*	*0.02*	*0.01*	*0.00*	*0.00*	*0.00*	*0.00*
Johansen cointegration test								
Cointegrating equations at 0.05 level — Trace statistic	0	1	0	1	1	1	1	2
Max-Eigenvalue statistic	0	1	1	1	0	1	1	2

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

Normality test of the residuals in the models with a quadratic transformation of the economic activity level is reached for all the equations except for the one that refers to this variables. Because of this the joint normality test is not significant, but inference is valid for the equations of interest.

Coefficients from the cointegration relationship must be interpreted with the opposite sign