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ENVIRONMENTAL KUZNETS CURVE WITH ADJUSTED NET SAVINGS AS A TRADE-OFF BETWEEN ENVIRONMENT AND DEVELOPMENT

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The Environmental Kuznets Curve (EKC) hypothesises that emissions first increase at low stages of development then decrease once a certain threshold has been reached. The EKC concept is usually used with per capita Gross Domestic Product as the explanatory variable. As others, we find mixed evidence, at best, of such a pattern for CO_2 emissions with respect to per capita GDP. We also show that the share of manufacture in GDP and governance/institutions play a significant role in the CO_2 emissions–income relationship. As GDP presents shortcomings in representing income, development in a broad perspective or human well-being, it is then replaced by the World Bank's Adjusted Net Savings (ANS, also known as Genuine Savings). Using the ANS as an explanatory variable, we show that the EKC is generally empirically supported for CO_2 emissions. We also show that human capital and natural capital are the main drivers of the downward sloping part of the EKC.

I. Introduction

The Kyoto protocol (KP) was negotiated in 1997 and establishes Greenhouse Gas (GHG) emission limits for developed nations – Annex I Countries – relative to their 1990 emission levels as a method for tackling global climate change. It entered into force after Russia ratified the Protocol late 2004 and participating OECD nations, with the notable exception of the USA that did not ratify the Protocol, committed to a reduction of 5.2% of GHG emissions compared to 1990 levels by 2012. The KP did not include any environmental restriction to the developing world as it might prevent those less-developed countries to increase their economic activity and raise their populations' standards of living, which should be their major objective.

The KP is an extension of the United Nations Framework Convention on Climate Change (UNFCCC), an international treaty negotiated in 1992 at Rio de Janeiro's Earth Summit by 172 national governments aiming at reducing (or, at least, stabilising) the concentration of GHG in the atmosphere. To that respect, it recognises the particular role played by developed countries and their responsibilities in today's situation, and therefore insists on the fact that they should act as leaders

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and adopt binding mitigation commitments. The parties of the UNFCCC have met annually to evaluate their progress in GHG emission reductions since 1995 at the Conference of the Parties (COP). Among the famous COP, we may highlight the COP3, held in Kyoto in 1997, where the KP has been negotiated, or the COP19, held in Doha in 2012, that extended KP's commitments for the period 2012–2020. Unfortunately, some industrialised countries such as Japan, Russia or New Zealand did not adopt any additional constraints, and Canada decided to withdraw from the KP in 2012. An additional step was reached with the COP21 decisions in December 2015 in France because many countries (including developing nations as well as industrialised countries without emission constraints) pledged to curb emissions and all participants agreed on keeping the average temperature rise compared to pre-industrial levels below 2 degrees centigrade.

The relation between GHG emission limits and economic growth, or more generally, between environmental damage and economic growth has been much debated these past decades. On that matter, the Environmental Kuznets Curve (EKC hereafter) hypothesis emerged in the end of the twentieth century with Grossman and Krueger (1991) and Shafik and Bandyopadhyay (1992). They built bridges between the environment–income relationship and the theory of Simon Kuznets (1955) postulating that inequalities in a country increase in earlier stages of development, then finally decrease once a certain income threshold has been reached, such that an inverted U-shaped relationship exists between inequalities and income. The EKC hypothesis claims the same is true for environmental degradations: At low levels of economic development, human behaviours do not impose an excessive stress on natural capital. But once the economy develops, the impact of human activity on natural resources increases, then finally decreases after some threshold in income has been overtaken. This leads to a claim that 'the best-and probably the only-way to attain a decent environment in most countries is to become rich' (Beckerman, 1992, p.491).

Being essentially an empirical phenomenon, the EKC is subject to much debate. The choice of the pollutant under study, for example, plays an important role in such a relationship. We can distinguish between local (suphur dioxide, particulate matters, among others) and global pollutants (carbon dioxide being the most important). While concentration or emissions of local pollutants frequently exhibit an inverted U shape with income, the result is much more ambiguous – to say the least – for global pollutants. Besides, one specific approach (time series, cross country or panel analysis) or using specific groups of countries or specific time periods leads to a specific relation, thereby preventing to generalise the existence of an EKC.

The development measure itself may also be questionable. Nearly all studies use per capita Gross Domestic Product (GDP) even though its shortcomings in representing development in a broad perspective or human well-being have been largely exposed. If GDP may be accepted as a correct measure of market activity, it clearly fails to represent welfare (Stiglitz *et al.,* 2009) and may also be, as explained later in the text, considered as a poor representation of income. Once environmental degradations have long-lasting effects for future generations, as is the case for CO_2 emissions, an alternative measure taking future generations into account might therefore be better suited. This is why we use the Adjusted Net Savings (ANS) (or Genuine Savings), an indicator that considers the productive base at the disposal of future generations (including physical, human and natural capital), so as to have a wider measure of development as well as a better approximation of income.

The remainder of the paper is organised as follows: Section II reviews the genesis of the EKC concept in the literature, as well as its shortcomings and possible alternatives, among which the ANS, considered in this paper. Section III presents the methodology and the data description. Section IV summarises the results, first with a standard measure of economic development, then with a sustainable development indicator such as ANS as the explanatory variable. Section V concludes.

II. The EKC Hypothesis: Genesis, Shortcomings and Alternatives

The EKC hypothesis can be addressed from both the demand and the supply sides. The former one implies that, at low income levels, the agents' main concern is directed towards increasing their incomes to fulfil natural needs, and therefore towards economic growth. This, in turn, implies a higher stress on the environment through an increase in natural resource consumption and in polluting emissions. Once richer, the agents will tend to give an additional value to a cleaner environment and will therefore invest a part of their income in its conservation to finally reduce environmental degradations (Dinda, 2004). On the supply side, the forces behind the EKC can be summarised in three different effects: The composition, the scale and the technique effects (Grossman & Krueger, 1991). The composition effect relates to the structure of the economy: at earlier stages of development, agriculture is the main driver of the economy, with a low stress on the environment; as income grows, heavy industries tend to grab a higher share of production, which leads to additional natural resource consumption and emissions (thus a higher environmental stress); later stages of development are then coupled with a shift toward a service-oriented economy, which implies a reduction in the environmental stress. The scale effect states that more production requires more input (and typically more natural resources) and therefore more pollution, given no technological change and no structural transformation of the economy. Finally, improvements in terms of productivity (less input required for the production process) and of emissions (cleaner technologies or changes in input-mix) tend to lower environmental degradations, which is the technique effect. Earlier stages of development are therefore assimilated to a supremacy of the scale effect on the technique effect while the opposite holds for later stages.

a) Genesis

The relation between environmental degradation and income can be tested empirically by a simple regression such as the following one:

$$y_{it} = \alpha_i + \beta_1 x_{it} + \beta_2 x_{it}^2 + \beta_3 x_{it}^3 + \beta_4 z_{it} + \varepsilon_{it} \tag{1}$$

where y is the environmental indicator of country i at time t, x represents income, z is a vector of other variables that might affect environmental degradations, α is the country specific effect[1] and ε the error term. The β parameters determine the shape of the environment–income relationship. If $\beta_2 = \beta_3 = 0$, it is monotonic (increasing if β_1 is positive, decreasing otherwise). If $\beta_3 = 0$, we either obtain an EKC (inverted U-shaped relationship) or a U-shaped curve. We can also obtain an EKC type curve in cubic form when a positive β is followed by a negative one (e.g. $\beta_1 > 0$, $\beta_2 > 0$ and/or $\beta_3 < 0$). Finally, the cubic relationship can also follow an N-shaped pattern, where the environment first deteriorates with income, gets better after a threshold and finally worsens again for high enough income; or an inverse N-curve. This regression might be estimated either with time-series, cross-sectional or panel data.

Grossman and Krueger (1991) were the first ones to observe this inverted U-shaped relationship between urban air pollution (sulphur dioxide and dark matter) and income in the United States. They then extended their analysis (Grossman & Krueger, 1995) to several other countries and

[1] Index '*i*' can also refer to a group of nations. In that case, individual dummies are replaced by group dummies. Our regressions mostly consider group-specific effects.

indicators related to air and water pollution. They found significant evidence of an EKC with a threshold per capita income of around $8000 (1985 USD) for most of the indicators studied. However, they were cautious enough not to generalise their findings. Rather, they mentioned that their study found that GDP growth does not contribute to worsen the environmental indicators under study. Other empirical studies followed and found similar results, mostly for local air pollutants having a direct impact on human health (among others Selden & Song, 1994).

b) Shortcomings

Even though an EKC is frequently obtained for specific local pollutants, the case of global pollutants such as carbon dioxide is at best rather mixed (see Kaika & Zervas, 2013, for an extensive review). On the one hand, Holtz-Eakin and Selden (1995) found an EKC using data for 130 countries between 1951 and 1986, but with a threshold per capita income of $35 428 (1986 USD), way outside the sample, which weakens their conclusion. Looking at logarithmic figures, they even found a threshold per capita income of $8 million. Panayotou *et al.* (2000) also found that CO_2 emissions follow an EKC pattern, but only for OECD countries. On the other hand, Coondoo and Dinda (2008) obtained a monotonically increasing relationship between CO_2 emissions and income in their 88 countries panel, although an EKC might be observed for Europe on its own. Faucheux *et al.* (2012) observed an N-shaped relationship between carbon dioxide emissions and income for Belgium, France, the United Kingdom and the United States for the years 1950–2008. Their worldwide analysis concluded that an EKC cannot be credibly confirmed as it would require a per capita threshold income that is twice its 2004 level (therefore far out of the sample).

Over the years, the methodology behind the EKC has been subject to numerous criticisms. Stern (2004) highlights the many econometrical flaws of the process, arguing that the issues of heteroskedasticity, cointegration, simultaneity or omitted variables bias render the model fragile. Those problems have been answered, to a certain extent, in the literature by econometric tests for the three former issues and by introducing additional explanatory variables for the latter one, in order to highlight the forces that could be responsible for this relationship.[2] For example, Torras and Boyce (1998) included income inequality (as well as literacy and liberty rights) and showed that it plays an important role in various pollutant emissions; Suri and Chapman (1998) added international trade in manufactured goods and showed that the upward (downward) part of the EKC might be explained by exports (imports) of such goods; Hettige *et al.* (2000) concluded that the share of industry in production also follows an EKC pattern compared to income, confirming the composition effect assumption; and Panayotou (1997) found that institutions and policies can seriously flatten the EKC pattern, at least for ambient SO_2 levels. Also, the role of institutions, particularly the role of international regulations in terms of CO_2 from the KP, has also been highlighted as a major factor for decoupling emissions and economic growth for OECD nations that ratified the Protocol (Faucheux *et al.,* 2012).

Another problem comes from the reduced-form regression: Kijima *et al.* (2010) argue that the choice of a cubic instead of a quadratic reduced-form will tend to determine the shape of the relationship. Given the expected signs for the estimated parameters and provided they are statistically significant, the quadratic form implies an EKC while a cubic one will tend to a N-shaped relationship. Furthermore, using the mean per capita income might not be the best representation (Stern,

[2] We simply mention the main papers concerning those issues. For an exhaustive review of this literature, see Kaika and Zervas (2013).

2004): because income distribution is highly skewed, most of it lies below the mean income; using the median income may therefore appear more relevant in this situation.

Others also point out the fact that cross-sectional (e.g. List & Gallet, 1999) and panel (e. g. De Bruyn *et al.,* 1998) data analyses are not able to predict developing countries' development paths. Finding a threshold income for such a sample, for example, does not imply that any single country will follow the same path in terms of environmental degradation in the future.

As seen earlier, the EKC is usually a concept that is applied to one pollutant at a time and Dasgupta *et al.* (2002) raise the problem of what they call 'new toxics', meaning that, despite the reductions of some known pollutants, industrial activity creates additional ones, potentially unregulated and more harmful to the environment. The example of nuclear energy is a good illustration of the problem: reducing CO_2 emissions compared to other energy producing devices may favour nuclear energy and create additional nuclear waste for which no satisfactory solution regarding long term disposal currently exists. Some authors attempt to circumvent the issue by using a wider environmental indicator as dependent variable that accounts for environmental quality as a whole: Dietz *et al.* (2012) construct the environmental intensity of human well-being, that is, the ratio of a nation's per capita ecological footprint to its average life expectancy at birth, and find that it obeys a U-shaped pattern with respect to income; Bagliani *et al.* (2008) and Caviglia-Harris *et al.* (2009) analyse the ecological footprint–income relationship and find no empirical evidence to conclude that an EKC exists.

Using the ecological footprint as a dependent variable also allows answering another criticism of the EKC concept, namely the pollution haven hypothesis that has been pinpointed since the early EKC studies (among others by Grossman & Krueger, 1995). This hypothesis assumes that, as countries develop and move to service-oriented economies, they import industrial pollution-intensive goods from less-developed economies. Their EKC's downward sloping part might just result from such international trade, but it would also mean that developing countries would not be able to follow a similar path as they might not find less-developed economies to produce their manufactured pollution-intensive output. One way to correct for international trade of pollution would be to look at a country's consumption instead of production, as can be done with the ecological footprint that provides both consumption and production data.

c) Measurement of income/development

While most EKC's shortcomings have been largely dealt with in the literature, the issue surrounding the measurement of development or income has been relatively left aside so far as nearly all past studies use per capita GDP. The fact that per capita GDP is a poor representation of a country's welfare or development has been highlighted by many studies (i.e. Kubiszewski *et al.,* 2013, and Stiglitz *et al.,* 2009). Munasinghe (1999), for example, argues that the relationship between environment and development would be better captured by a welfare indicator, such as green national income or genuine savings. He further states that 'developing countries could learn from the past experiences of the industrialised world by adopting measures which would permit them to 'tunnel' through the EKC' (Munasinghe, 1999, p.96). In other words, adopting sustainable policy measures and focusing on genuine savings instead of per capita GDP, for example, should allow them to develop in a broad sense at a lower environmental cost.

Furthermore, per capita GDP may also be considered as a poor representation of income. Indeed, Hicks (1946) considers income as the revenue an agent might consume without impoverishing himself for the following periods, a notion that is therefore relatively close to sustainable development.

Neumayer (2004), in a similar vein, states that 'GDP is a particularly erroneous measure of income for resource-intensive economies' (Neumayer, 2004, p.1627) because it includes the depreciation of produced capital and natural capital, which is particularly high in oil-exporting countries. Franklin and Ruth (2012) go even further by stating that GDP includes some measure of pollution because expenditures made to mitigate or offset the negative environmental externalities of the industrialisation process (e.g. healthcare or abatement expenditures) are present in its computation.

Several studies follow this line of work and use other measures of income or welfare as explanatory variable in equation (1). For example, Hill and Magnani (2002) analyse the emissions of carbon dioxide, sulphur oxide and nitrous oxide relative to the human development index (HDI) in a panel data to find that the EKC hypothesis vanishes for carbon dioxide and sulphur oxide (whose emissions either follow an N-shaped pattern or are monotonically increasing), while nitrous oxide emissions are decreasing in the HDI. And Franklin and Ruth (2012) look at the behaviour of CO_2 emissions with respect to the Genuine Progress Indicator (GPI) for the United States between 1950 and 2000 and obtain significant evidence to conclude for an EKC.

d) The ANS as an alternative to GDP

In our analysis, we follow Munasinghe (1999) and use the World Bank's Adjusted Net Saving (ANS), also known as genuine savings, as explanatory variable. As an indicator of sustainable development that takes into account the depreciation of fixed capital as well as the consumption of natural resources or some of the costs associated to pollution, the ANS answers the previously exposed criticisms made to GDP on its representativeness of income. As mentioned by Franklin and Ruth (2012), the EKC may be augmented to better reflect development rather than simply economic growth. Instead of using the HDI like in Hill and Magnani (2002), we prefer to use a better approximation of income rather than a totally different alternative to GDP, and we concentrate on ANS and not on GPI as in Franklin and Ruth (2012) because the large data availability for many countries over a reasonable period of time enables a more comprehensive analysis than with GPI.

Even though the ANS also suffers from various shortcomings that are detailed below, it emerged as one of the most influential indicators, as illustrated by its position in the *System of Environmental-Economic Accounting* (SEEA) of the United Nations Organizations and in the *Report of the Commission on the Measurement of Economic Performance and Social Progress* (Stiglitz *et al.,* 2009). Besides, given the intertemporal issues related to CO_2, using a measure of sustainability that includes development possibilities for future generations allows accounting for those long lasting effects.

The methodological presentation of the ANS relies mainly on Hamilton and Clemens (1999) and on the World Bank's *The Changing Wealth of Nations* (World Bank, 2011). The idea behind this measure is to look at the productive base of an economy (also seen as the wealth of a country) and its evolution. The productive base does not depend on physical capital alone, but also on human and natural capital. What is important in terms of sustainability is that this productive base should not decline over time, in order to allow future generations to enjoy at least the same level of welfare as the current one. The ANS reflects the evolution of such a nation's global wealth, negative figures representing a nation on an unsustainable path. This measure depends on the hypothesis of perfect substitution between those three forms of assets (physical, human and natural capital) and can thus be seen as an indicator of weak sustainability (as opposed to an indicator of strong sustainability like the Ecological Footprint where natural capital should be non-declining). The ANS can be computed as in equation (2):

$$\text{ANS} = \text{NS} + \text{EE–ED–MD–NFD–}(\text{CO}_2 + \text{PM}) \tag{2}$$

The first component consists of a nation's net saving (NS, its physical capital part), which is its Gross Saving minus the depreciation of fixed capital. Education expenditures (EE, net of fixed capital investment in buildings and infrastructure) are then added to reflect human capital and the depletion of natural resources is subtracted. Natural resource stocks include energy depletion (ED: coal, crude oil and natural gas), mineral depletion (MD: tin, gold, lead, zinc, iron, copper, nickel, silver, bauxite and phosphate) and net forest depletion (NFD: calculated as the product of unit resource rents and the excess of round wood harvest over natural growth). All those stocks are estimated in US$ as the ratio of the value of the resource stock to its remaining lifetime using the El Serafy method,[3] in order to answer Dietz and Neumayer's (2004) criticisms. Finally, the damage costs associated to CO_2 (evaluated at a fixed cost of 20$ per ton, in 1995USD) and particulate emissions (PM: evaluated as the willingness to pay to avoid mortality attributable to particulate emissions) are subtracted to obtain the final figure. In this study, we do not consider the damages from CO_2 emissions for preventing their presence in both the dependent and the explanatory variables.[4] Most ANS studies are expressed in percentage of the Gross National Income (GNI), therefore dividing equation (2) by the GNI.

Arrow *et al.* (2004) extend the ANS concept to account for population growth and technological change. This methodology requires additional data such as total factor productivity, but its computation in national accounts does not integrate natural resources as an input in the economy. In our analysis, we therefore do not use this extension of the ANS but rather the per capita value of Genuine Savings.

There are various criticisms about ANS computations. For example, Dietz and Neumayer (2004) argue that the ANS framework relies on the strong assumption of inter-temporal efficiency of the markets. The human capital computation from education expenditures is also criticised by Thiry and Cassiers (2010) who believe that an outcome valuation, rather than an input perspective, might better reflect the evolution of human capital.

The estimation of the natural capital stock (including pollution) raises the largest debate around the ANS. Indeed, its computation only considers the polluting country and not the country consuming the environmental bad and in addition, the use of market prices in an imperfectly competitive market with externalities also underestimates natural stock depletion (Thiry & Cassiers, 2010). Another underestimation comes from missing natural resources like fisheries, water resources, air and water pollutants, soil and biodiversity, … because of the lack of available data (Arrow *et al.,* 2004). Furthermore, using a fixed price for carbon damages (20$ per ton) and using a behavioural approach, like the willingness to pay to avoid incumbent mortality, for determining the cost of particulate emissions damage, are also matter of debate among researchers (Neumayer, 2000).

Finally, Pillarisetti (2005) and Everett and Wilks (1999) show that countries exhibiting high GDP levels are far more likely to obtain high values in their investment in both human and physical capital, while their wealth rarely varies with changes in natural capital. A simple Weighted Least Squares (WLS) regression indeed shows that ANS varies positively with GDP and that the two

[3] The El Serafy method uses the remaining lifetime of the resource under study to value its capital stock, with the following formula: $(P - AC) \times R \times \left[\frac{1}{(1+r)^{n+1}}\right]$ where P stands for resource prices, MC for marginal cost (approximated in this case by average cost – AC – for simplification), R is the volume of extraction, r is the discount rate and n the anticipated lifetime of a resource (the number of years for a particular stock)

[4] We are grateful to one reviewer who pointed out this aspect during a seminar presentation.

series are highly correlated. However, ANS is a larger development measure than income because a rich country that would drain most of its GDP out of natural resources and polluting activities is likely to see its ANS drop; this is exactly what happens for Saudi Arabia.

Even though the ANS has been unable to raise a large consensus on its methodological and ideological relevance, a minority (or perhaps even none) of its distractors would probably assert that it is a poorer representation of development or income than GDP. As it includes natural and human capital in addition to the traditional man-made capital, it clearly seems to be a relevant measure of development in an EKC framework.

III. Data Description

This paper considers a single pollutant: carbon dioxide emissions. This choice comes from the fact that climate change is one of the most important environmental concerns. Besides, carbon dioxide emissions account for more than half of the ecological footprint, one of the most notorious environmental indicator, especially for high-income countries (Global Footprint Network, 2008).

CO_2 data are taken from the Carbon Dioxide Information Analysis Centre (CDIAC) of the U.S. Department of Energy (Boden *et al.,* 2013). Another database that is frequently used in EKC studies is provided by the International Energy Agency (IEA). Both databases construct their data using estimates on fossil fuel burning, cement production and gas flaring (only fossil fuel burning for the IEA database) provided by the United Nations (the U.S. Department of Interior's Bureau of Mines for cement production). Those numbers are converted into per capita metric tons of carbon using emission coefficients. The difference between the two databases comes from the fact that the CDIAC uses a single coefficient for gas, oil and solid fossil fuels while the IEA applies specific coefficients. Despite those differences, both series provide similar results for EKC analyses (Galeotti *et al.,* 2006).

GDP and ANS data come from the World Bank's World Development Indicator (World Bank, 2014) and are computed in 2005 USD. ANS figures include damage costs associated to particulate emission while the costs associated to CO_2 emissions have been removed. Other explanatory variables such as trade in manufactured products or the share of manufacture in the economy also come from the World Development Indicator and have been tested for significance and converted to 2005 USD.

Finally, we analyse the impact of governance by using two different indicators, a qualitative indicator (labelled 'governance') that reflects global governance and a second one, labelled 'Kyoto', for which we integrate a dummy variable to isolate countries that ratified the Protocol with binding commitments, starting in 1997. The 'Governance' indicator is derived from the Worldwide Governance Indicators (World Bank, 2013), constructed with 32 data sources of 4 types: surveys of households and firms; commercial business information providers; non-governmental organisations; and public sector organisations (see Kaufmann *et al.,* 2010, for methodological description). We aggregated their six indicators (Voice and Accountability, Political Stability and Absence of Violence, Government Effectiveness, Regulatory Quality, Rule of Law and Control of Corruption) using a simple mean value. As those indicators all range from -2.5 to $+2.5$, our final governance indicator also falls in the same range, a higher score meaning better institutions. Even though this database covers a wide range of countries, it only provides data since 1996, therefore lowering the number of observations in our analysis.

Because ANS is not available for all nations, this analysis is conducted on a sample of countries that represent as many characteristics of the world economy as possible. We first adapted the

Table I Groups of countries in the sample

High income	*Middle income*	*Low income*
Australia	Botswana	Burundi
Canada	Brazil	Ghana
Germany	China	Kenya
Japan	Colombia	Mozambique
Korea	Costa Rica	Niger
Netherlands	Egypt	
New Zealand	India	
Saudi Arabia	Indonesia	
Singapore	Russia	
Sweden	South Africa	
UK	Turkey	
USA		

classification made by Pretty (2013), dividing countries in seven groups: Affluent North, Affluent Asia, BRIC (Brazil, Russia, India and China), CIVETS (Colombia, Indonesia, Vietnam, Egypt, Turkey and South Africa), Resource Extractors, Poor Green and Poor Brown countries. Unfortunately, this classification does not provide enough information per group. We therefore re-classified these countries according to their 2010 per capita GDP using benchmarks corresponding to important income gaps in the sample distribution: low income (less than 1500 USD), middle income (from 1500 USD to 25 000 USD) and high income countries (more than 25 000 USD).[5] The list of the 28 sample countries is presented in Table I: it covers 72% of the world's GDP and 61% of the world population. Because of ANS data availability, we restricted our analysis to the period 1990–2010.

IV. Estimation Results

a) Group analysis

The results for the countries aggregated into low, medium and high income groups are presented in Table II. Weighted Least Squares (WLS) has been used to test equation (1) to correct for heteroskedasticity and autocorrelation.

Table II shows that, in both low-income and high-income groups, CO_2 emissions follow a cubic pattern that seems very similar to an EKC.[6] However, the threshold income at which emissions are supposed to decrease for the former group is 2725 US$ per capita, which is only reached once by two countries (Ghana and Kenya) around the year 2000 as those countries later experienced a dramatic decrease in their per capita GDP. For the latter group, the threshold income is 40 735 US$, which is more commonly reached (39 out of 251 observations). Finally, the middle-income group displays no significant relationship between both variables.

The R^2 statistics is quite high for the low-income group (0.71) but much lower for the two others (0.21 and 0.32, respectively, for middle and high-income groups), therefore rendering those regressions globally insignificant. The low adjusted R^2 experienced by the middle-income group is principally because of three countries of the sample: Russia, South Africa and China, whose emissions

[5] Unless otherwise mentioned, from now on, all figures are expressed in 2005 USD.
[6] The signs show a first reduction at very low GDP levels before displaying an EKC. In other words, it is an inverse N relationship, very similar to an EKC.

Table II Group analysis: CO_2 emissions versus GDP

	Low Income	*Middle Income*	*High Income*
Constant	2.30E + 01 (2.06)**	1.33E + 02 (1.00)	3.08E + 03 (3.17)***
GDP	−3.92E − 02 (−1.41)	6.63E − 02 (1.02)	−2.40E − 01 (−2.40)**
GDP^2	7.36E − 05 (3.56)***	−3.85E − 06 (−0.38)	1.37E − 05 (4.14)***
GDP^3	−1.80E − 08 (−4.04)***	2.20E − 10 (0.49)	−1.76E − 10 (−5.12)***
Adjusted R^2	0.71	0.21	0.32
N	105	229	251

Notes: ***, ** and * represent statistical significance, respectively, at the 99, 95 and 90% level. Student's *t*-statistics are given in parentheses.

in 2010 are respectively about six, three and five times higher than the rest of the group. Excluding them significantly affects the results as the relationship would then be monotonically linear (significant at the 90% level) and with a higher adjusted R^2 (0.71). The low adjusted R^2 of the high-income group, on the other hand, is not the cause of some outliers but only reflects the wide differences between the countries composing the group.

The main interest of such an analysis is to determine how each group behaves over time with the help of temporal dummies (not displayed in Table II). Roberts and Grimes (1997) and Hill and Magnani (2002) find that most dummies are negative for the high-income countries but positive for the two other groups, especially toward the end of the period. They conclude from their results that an EKC, if it appears, is only because of a relatively small proportion of wealthy countries that manage to cut down their carbon dioxide emissions (their carbon intensity in their study) while the rest of the world observes a worsening of their situation, especially the middle-income countries experiencing a dramatic surge in their emissions over the last years of the sample. Our results are consistent with theirs in the sense that high-income countries tend to have significant negative values for the temporal dummies' coefficients during the second half of the sample while middle-income countries experience positive numbers (significant for the last 3 years of the sample[7]).

b) Overall sample analysis

Testing equation (1) for the overall sample allows us to draw broader conclusions on the relationship between environmental pressure (represented by CO_2 emissions) and economic growth and to highlight the particular role played by omitted variables. Table III presents those results, first in a simple OLS (Ordinary Least Squares) regression, in order to show several econometrical tests such as the White test for heteroskedasticity or Ramsey's Reset test for appropriate specification (no omitted variables), then in a WLS framework in order to correct for heteroskedasticity and autocorrelation as before. Both regression types have been conducted in a simple environment–income relationship including only per capita GDP as an explanatory variable as well as temporal and group dummies (columns *I* in Table III) and then adding omitted explanatory variables (Columns *II*).

The R^2 statistics show that the relationships are rather robust, as all of them are above 0.7 (and above 0.9 for the WLS regressions). Including additional explanatory variables also improves the fit of the regression, as all adjusted R^2 in columns *II* are superior to their counterparts in columns *I*. In the OLS, the RESET test confirms the presence of omitted variables in both columns, even though the test statistic is much lower in column *II*, implying a better specification. The positive

[7] Excluding China and South Africa and Russia even enhances this result since the values for the last 10 years are then significant and positive.

Table III OLS and WLS on the overall sample with (columns *II*) and without (columns I) additional explanatory variables

	OLS		*WLS*	
	I	*II*	*I*	*II*
Constant	7.80E + 01 (0.42)	−2.41E + 02 (−0.92)	4.02E + 00 (0.09)	−8.92E + 01 (−1.15)
GDP	3.83E − 02 (1.32)	9.54E − 02 (2.31)**	3.07E − 03 (0.30)	9.52E − 03 (0.70)
GDP^2	6.51E − 06 (5.00)***	4.65E − 06 (2.58)**	5.61E − 06 (8.91)***	5.36E − 06 (6.72)***
GDP^3	−1.19E − 10 (−6.88)***	−9.62E − 11 (−4.19)***	−9.83E − 11 (−10.17)***	−9.48E − 11 (−8.17)***
Rich	−218.75 (−0.69)	−935.32 (−1.78)*	1071.1 (8.14)***	1045.45 (4.95)***
Medium	278.58 (1.70)*	−16.43 (−0.06)	267.65 (7.74)***	265.38 (4.44)***
Kyoto	−428.27 (−3.61)***	−37.52 (−0.22)	−792.25 (−10.86)***	−693.41 (−7.62)***
Manufacture	—	7.92E − 10 (4.96)***	—	9.65E − 10 (20.00)***
Imports	—	−3.04E − 01 (−0.51)	—	6.10E − 02 (0.34)
Governance	—	−289.78 (−3.48)***	—	−167.9 (−5.35)***
Adjusted R^2	0.72	0.74	0.93	0.95
N	585	326	585	326
RESET	44.79***	5.61***	—	—
WHITE	320.13***	219.31***	—	—

Notes: ***, ** and * represent statistical significance, respectively, at the 99, 95 and 90% level. Student's *t*-statistics are given in parenthesis.

first-order autocorrelation (the Durbin–Watson test is not presented in Table III), combined with the presence of heteroskedasticity confirmed by the WHITE statistics, tends to prefer a WLS to an OLS regression framework.

GDP coefficients give almost similar results in all columns: While GDP is significant and positive only in OLS *II*, GDP^2 and GDP^3 are always significant, the former one being positive while the latter one is negative in all cases. This implies that a cubic curve, similar in shape to an EKC, seems valid for CO_2 emissions for the global sample, although the threshold incomes are relatively high (between 36 500 USD and 40 400 USD) and reached by less than one tenth of the observations.

The group dummies, labelled Rich and Medium in Table III for the high-income and the middle-income groups respectively, are not significant in OLS regressions (except for OLS *II*, but only at the 90% level) while they give expected results for WLS regressions: both of them are significant at the 99% level and positive when compared to the reference group of low-income countries. This implies that richer countries have the overall tendency to emit more CO_2 than poorer ones, a result that is widely accepted.

Introducing additional explanatory variables may sometimes improve the specification. We therefore add one additional explanatory variable at a time and check with the RESET statistic whether the additional variable is relevant and improves the specification. To illustrate the composition effect, the manufacture share in GDP is the most interesting variable. To highlight the role of trade in CO_2 emissions and to test for the pollution haven hypothesis, we consider import, export and net export of manufactured products and keep imports as the most influential variable. Finally, our two governance indicators are added. While the impacts of manufacture and governance seem undeniable (statistical significance at the 99% level), the role of trade in the manufacturing sector is not significant, which means that the existence of pollution havens, stating that high-income countries reduce their emissions thanks to the outsourcing of polluting industries, as observed by Suri and Chapman (1998), is not supported empirically with this simple regression. The share of the manufacturing sector in a country's economy has a positive impact on its CO_2 emissions. This result reinforces the composition effect hypothesis of the EKC: The more important the manufacturing sector, the higher the CO_2 emissions. On the other hand, the role of governance and the quality of institutions, reflected by the global governance indicator as well as the Kyoto specific effect, play a negative role on CO_2 emissions, a result that is quite usual in the EKC literature.

c) Alternative sample

The results provided here may at best suggest that a worldwide EKC type curve seems valid for carbon dioxide even though the income threshold is very high. Nonetheless, a more precise look at CO_2 emissions and GDP data enables to detect a serious outlier: Singapore. Indeed, Singapore managed to increase its per capita GDP by 83% over the period (an annual growth rate of 2.9%) whilst cutting down emissions (in per capita terms) by 83% (an annual growth rate of −8%). Given those very specific CO_2 data and because Singapore represents almost a quarter of the observations over the income thresholds found in Table III, one might expect such a country to play an important role in the shape of the curve.

The particularity of Singapore is its total urbanisation rate, as it is known as a 'city-state'. As only three sovereign city-states are currently recognised (the two others are the Vatican and the Principality of Monaco, whilst non-sovereign city-states include among others Hong Kong, Macau and Gibraltar), they may indeed be seen as outliers compared to other countries. One would reasonably expect highly developed city-states to be much more able than others to drastically cut down their emissions because they are totally constrained by their fully-urbanised territories. The Vatican, for example, is targeting carbon neutrality, a policy that only a few nations would be able to follow in a near future.

In analysing the relationship between CO_2 emissions and economic growth for predicting possible development paths of emerging nations, excluding city-states of the sample would not harm the analysis as such a development path would not be accessible to every nation (or even, most). Besides, Singapore only accounts for 0.3% of the world's GDP and 0.07% of the world's population; therefore, such a removal does not affect the representativeness of our sample. Finally, one could argue that, given the presence of Singapore, nothing would prevent the Vatican, Monaco or even Hong Kong to be included in our sample, which would significantly alter our results as their development path is relatively similar to Singapore's (World Bank, 2014, and UNFCCC, 2015).

Table IV presents the regressions' results for OLS (two first columns) and WLS (two last columns) for the sample without Singapore. All regressions include temporal as well as group dummies and columns *II* introduce the same additional explanatory variables as before, while columns *I* only have GDP as independent variable.

Compared to Table III, all adjusted R^2 coefficients are relatively similar. Again, introducing additional variables improves the fit of our regressions. Furthermore, the RESET test statistics are now much lower than in Table III and even reject the null hypothesis of no omitted variables at the 90% level in columns *II*, thus again favouring WLS *II* over the others.

The relationship for the alternative sample has now become linearly positive for all columns but WLS *I* where a cubic EKC-type pattern appears. However, the threshold income at which emissions are supposed to decline is far out of the sample (51 000 USD while the largest per capita income observed in 2010 is close to 44 000 USD). Given that relatively high income threshold and the fact that WLS *II* should be preferred over the other specifications, we may conclude that the EKC is not an empirically valid hypothesis once Singapore is excluded of our sample. Adding group dummies and additional explanatory variables gives results that are similar to the former analysis; hence, they are not specified again here.

We can therefore conclude that excluding Singapore from the sample significantly affects the results without altering the sample's representation of the characteristics of the world economy. The new specification shows even more that the EKC is not a valid hypothesis for CO_2 emissions. Besides, this new sample analysis confirms the conclusions mentioned in the previous section: EKCs, when they appear, are because of some isolated wealthy countries that managed to cut down emissions (Singapore, in this case, with its 8% annual reduction).

d) The ANS as an alternative development measure

For overcoming GDP's poor representation of development and income, the analysis now replaces per capita GDP by per capita ANS. The ANS analysis presented here essentially considers the sample without Singapore for the reasons explained above. Meanwhile, whenever results differ when Singapore is added, the differences will be highlighted.

We group countries according to their 2010 per capita ANS into High (ANS $>$ 1500USD), Middle (1500 $>$ ANS $>$ 150USD) and Low ANS (150USD $>$ ANS). Because the new group differentiation does not enable us to compare the ANS and GDP group analyses, it seems that the group analysis has a more limited interest[8] and we will thus directly consider the whole sample. Results

[8] All three WLS regressions show relatively weak adjusted R^2 coefficients, comforting us on this analysis' limited interest.

Table IV OLS and WLS on the overall sample with (columns *II*) and without (columns I) additional explanatory variables, excluding Singapore

	OLS		*WLS*	
	I	*II*	*I*	*II*
Constant	−10.13 (−0.05)	−244.65 (−0.92)	−3.24E + 01 (−0.81)	−126.07 (−1.59)
GDP	1.20E − 01 (3.60)***	1.78E − 01 (3.79)***	4.42E − 02 (4.27)***	7.02E − 02 (4.14)***
GDP^2	−3.72E − 08 (−0.02)	−2.43E − 06 (−0.90)	1.54E − 06 (2.09)**	−4.36E − 07 (−0.38)
GDP^3	−8.48E + 00 (−0.30)	2.19E − 11 (0.55)	−2.59E − 11 (−2.06)**	2.13E − 12 (0.11)
Rich	72 (0.23)	−365.53 (−0.66)	1318.75 (12.33)***	1543.5 (7.52)***
Medium	109.85 (0.67)	−155.53 (−0.61)	213.71 (7.66)***	182.07 (2.71)***
Kyoto	−315.69 (−2.60)***	74.86 (0.44)	−576.34 (−7.96)***	−516.67 (−4.78)***
Manufacture	—	6.23E − 10 (3.87)***	—	9.11E − 10 (14.10)***
Imports	—	−3.09E − 01 (−0.49)	—	9.87E − 02 (0.57)
Governance	—	−273.51 (−3.35)***	—	−138.93 (−4.46)***
Adjusted R^2	0.73	0.76	0.93	0.94
N	564	314	564	314
RESET	27.53***	2.43*	—	—
WHITE	299.70***	219.99***	—	—

Notes: ***, ** and * represent statistical significance, respectively, at the 99, 95 and 90% level. Student's *t*-statistics are given in parenthesis.

Table V OLS and WLS on the overall sample with (columns *II*) and without (columns I) additional explanatory variables

	OLS		*WLS*	
	I	*II*	*I*	*II*
Constant	130.21 (0.56)	124.63 (0.45)	6.76E + 01 (1.99)**	168.44 (3.27)***
ANS	1.07E + 00 (7.40)***	1.23E + 00 (4.92)***	8.40E − 01 (8.81)***	1.15E + 00 (8.47)***
ANS^2	−2.20E − 04 (−5.67)***	−2.45E − 04 (−4.58)***	−1.57E − 04 (−7.13)***	−2.08E − 04 (−7.73)***
ANS^3	1.05E − 08 (3.67)***	1.22E − 08 (3.55)***	7.35E − 09 (4.61)***	9.79E − 09 (6.04)***
ANS Rich	1693.62 (7.87)***	1155.45 (2.97)	1618.11 (10.19)***	785.43 (3.03)***
ANS Medium	759.71 (5.70)***	383.88 (2.09)**	445.14 (7.89)***	3.61 (0.05)
Kyoto	117.28 (0.72)	55.78 (0.26)	93.04 (1.02)	−60.06 (−0.33)
Manufacture	—	9.74E − 10 (4.51)***	—	9.75E − 10 (5.53)***
Imports	—	−1.65E − 01 (−0.24)	—	−2.47E − 01 (−2.32)**
Governance	—	−5.68 (−0.06)	—	30.91 (1.61)
Adjusted R^2	0.55	0.65	0.89	0.86
N	560	313	560	313
RESET	14.63***	8.52***	—	—
WHITE	468.1***	251.70***	—	—

Notes: ***, ** and * represent statistical significance, respectively, at the 99, 95 and 90% level. Student's *t*-statistics are given in parenthesis.

are displayed in Table V with ANS as independent variable, time dummy variables and group dummies that now depend on the ANS level instead of GDP.

As in Tables III and IV, WLS *II* seems to be the best specification. The RESET test statistic is lower for OLS *II,* even though the null hypothesis of no omitted variables is still rejected at the 99% level, which favours the presence of additional explanatory variables. Finally, autocorrelation and heteroskedasticity are still an issue, thus lending support to the WLS method.

Nonetheless, the results are similar in all columns and suggest that the relationship between CO_2 emissions and per capita ANS follows an N-shaped pattern with a reasonable initial threshold at which emissions are supposed to decline (between 3100 USD and 3800 USD). The second threshold above which emissions revert back up is much higher and far out of the sample (around 10 500 USD for all columns), thus lending support to a cubic relationship similar in shape to an EKC.

While the manufacture variable is similar to what is found in Tables III and IV, the two other additional variables are now totally different. Imports of manufactured goods have become significant at the 95% level with a negative sign in the WLS regression: importing more goods therefore lowers a country's CO_2 emissions, a result in favour of the pollution haven hypothesis. The governance indicator and the Kyoto specific effect, on the other hand, are now insignificant even at the 90% level. Such a result may be interpreted by the fact that ANS is a wider concept of development than GDP and may thus incorporate some aspects of governance and institutions in its figures. Furthermore, the Kyoto specific effect may be integrated in the high-ANS group specific effect because 9 out of 10 countries in that group have emission reduction targets for the KP (in comparison to 9 out of 12 countries in the high-income group).

We have seen that analysing CO_2 emissions relative to per capita GDP and per capita ANS yields fairly different results. While the former one supposes a monotonically increasing relationship (or an EKC type curve if Singapore is part of the sample), the latter seems to confirm that an EKC type curve may occur at a reasonable threshold. Those differences might be explained as follows. Knowing that the ANS is constructed on the concept of a productive base and its three components (man-made, human and natural capital), one would reasonably expect the first component to be positively correlated to emissions (because it increases the scale effect) while the other two vary in the opposite direction: the literacy rate (similar to education and used to represent human capital) tends to act negatively on pollution (Torras & Boyce, 1998) and so does natural capital. The final step of the analysis looks at the importance of those three components and the results are indeed in conformity to our expectations.

Table VI presents the coefficients obtained by estimating equation (1) with the three different components of the Adjusted Net Savings separately. WLS regressions have been conducted on

Table VI Overall analysis with the three components of ANS

	Man-made capital	*Human capital*	*Natural resource depletion*
Constant	5.05E + 01 (1.39)	−9.13 (−0.43)	−1.23E + 02 (−2.18)**
ANS-component	7.71E − 01 (8.69)***	5.09E + 00 (20.07)***	4.40E + 00 (21.16)***
ANS-component^2	−1.98E − 04 (−6.17)***	−2.07E − 03 (−8.56)***	−2.13E − 03 (−11.54)***
ANS-component^3	1.47E − 08 (4.28)***	1.76E − 07 (2.72)***	3.01E − 07 (7.81)***
ANS Rich	2019.59 (21.95)***	−359.41 (−2.77)***	1870.95 (35.43)***
ANS Medium	528.69 (9.33)***	308.07 (14.13)***	749.1 (20.59)***
Adjusted R^2	0.92	0.88	0.9
N	560	564	564

Notes: ***, ** and * represent statistical significance respectively at the 99, 95 and 90% level. Student's *t*-statistics are given in parenthesis.

the sample without Singapore. Adding Singapore, additional explanatory variables, removing the group dummies or using OLS (not shown in Table VI) yields similar coefficients both in significance and in magnitudes. The relationships therefore seem rather robust.

The adjusted R^2 coefficients are relatively high in all three regressions, group dummies are always significant and have the expected signs and nearly all coefficients are significant at the 99% level. We obtain N-shaped curves for two regressions: man-made capital and natural capital depletion, and an EKC for human capital with a threshold of 1500 USD. Concerning man-made capital, emissions tend to stabilise after the initial threshold (2800 USD) instead of sharply declining, and then take off again once the second threshold (6100 USD) has been overcome. Concerning natural capital depletion, one would have expected a monotonically increasing relationship between emissions and natural resource depletion instead of a N-shaped curve. However, more than 95% of the observations occur before the first threshold (1500 USD), implying that the N-shaped relation is clearly because of some outliers with very high resource depletion levels. Indeed, if Saudi Arabia[9] is excluded, for example, the relation becomes monotonically increasing, a result that confirms initial expectations. Finally, the result for human capital shows that at low levels, investing more in human capital acts positively on emissions, but it then acts negatively on emissions once a certain threshold has been reached (which is the case for about 21% of our observations).

V. Conclusion

This paper evaluates the existence of an EKC between carbon dioxide emissions and economic development. Past studies have shown that the concentration of local or regional pollutants like particulate matters or sulphur dioxide tend to increase at earlier stages of economic development, and then finally decrease once a sufficient income has been reached, a relationship known as the EKC. The case of carbon dioxide emissions, on the other hand, obtained mixed evidence – at best – of such a relationship in the literature. This paper shows that results vary depending on the sample under study. If Singapore is included in the sample, CO_2 emissions might seem to follow an EKC-type pattern but the income threshold is relatively high and not often reached. On the other hand, excluding Singapore from the sample leads to a monotonically increasing relationship between emissions and per capita GDP. This paper also highlights the fact that EKCs, when they arise, may be because of some high-income countries experiencing reductions in their CO_2 emissions towards the end of the period, which is mostly because of the KP, and/or to specific outliers like the City-State of Singapore. Hence, such a result cannot be extended to other countries or generalised worldwide.

Using a measure of sustainable development instead of income as the explanatory variable gives quite different results: When the Adjusted Net Savings replaces per capita GDP, an EKC relationship generally appears at reasonable thresholds. When an economy develops in a broader way, taking into account the welfare of future generations, CO_2 emissions tend to first increase and then finally decrease, once a threshold ANS has been reached. However, one can argue that such an ANS level remains quite high and out of reach for developing countries in the near future, but it allows showing that such alternative development may sooner or later be negatively correlated to CO_2 emissions. Among the components of the ANS, man-made capital and natural resource depletion tend to increase CO_2 emissions while the reverse is true for human capital after some threshold has been reached.

[9] Saudi Arabia has the particularity of being an oil-exporting country with a very high energy depletion part in the Environment accountability.

Our results also show that the composition of the economy (captured here by the share of manufacture in GDP) significantly affects the relationship between environment and development. However, not all countries will be able to turn to service-oriented economies, as manufactured products still have to be produced somewhere. If developed economies were able to take such a turn, it is mostly because of globalisation and the outsourcing of manufactured products to less-developed countries. Nonetheless, this cannot be generalised as a development path for all, as it would always require manufacturing goods production in less-developed countries.[10] Furthermore, our analysis confirms the importance of good institutions/governance practices in CO_2 emission reductions. Unsurprisingly, it also confirms the important role played by international commitments, such as the KP, that clearly drive emissions down.

Finally, we have shown that excluding a single country (Singapore) can significantly affect the environment–income relationship. Also, becoming richer (higher GDP) is not necessarily positive for the environment. On the other hand, becoming sufficiently sustainable (captured by the ANS) pairs with lower emissions. And more precisely, CO_2 emissions decrease when ANS increases through its human and natural capital components.

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[10] Note that it does not mean that this confirms the pollution haven hypothesis: as a matter of fact, in this analysis, trade variable is only significant with ANS.

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