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A MODIFIED ENVIRONMENTAL KUZNETS CURVE FOR SUSTAINABLE DEVELOPMENT ASSESSMENT USING PANEL DATA

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A Modified Environmental Kuznets Curve for Sustainable Development Assessment Using Panel Data

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Abstract
Sustainable development is a concept strictly connected with basic needs of the individuals. During last years a number of empirical studies have tried to discover and quantify the causal relations between economic growth and environmental consumption and degradation. The most widely used empirical model is the so-called Environmental Kuznets Curve (EKC), nowadays applied to different polluting elements. Despite the huge diffusion of EKC studies, this model has been criticised for incompleteness of a sustainable development analysis. The aim of this paper is to build a Modified EKC (MEKC) in order to consider a wider concept of development rather than pure economic growth, including well-being aspects and sustainability of the development process. Using a macroeconomic measure of sustainability such the World Bank's *Genuine Saving* and a measure of well-being such the United Nations' *Human Development Index*, we build a model in order to analyse linkages between higher welfare levels and natural resources consumption, verifying the sustainability of human development. A panel analysis for three years (1990-1995-2000) for a wide range of countries (including developed and developing countries) has been applied in order to respond to criticisms related to conjunctural results linked to pure cross-section studies. Comparisons among alternative pollutants (i.e., CO_2, NO_X, and SO_X) and GS are described, and the robustness of the MEKC clearly emerges. Furthermore, in order to respond to criticisms for the reduced form of the EKC, an Instrumental Variables model has been tested both on CO2 and GS, while a system of equations has been tested considering simultaneously a traditional EKC and a MEKC for a longer time period (1996-2004). Unit root tests for non-stationary series have been computed, showing that the IV model gives satisfactory results. An indicator for technological capabilities has been added at this stage, accounting for diffusion of technical progress and import technology as suggested by Archibugi and Coco (2004). Causal relations individuated within a MEKC allow to identifying correlation between human development and sustainable development, following the classic inverted *U*-shaped curve of the EKC. Nonetheless, comparing the turning points of the respectively MEKC and EKC, it seems that using this alternative specification some useful policy implications apply. The threshold level of human development in the MEKC corresponds to a income per capita level lower than the threshold level for the EKC, confirming the possibility of "tunnelling through the curve" as suggested in Munasinghe (1999). Our results show that human development should be the first objective of international development policies, and an increase in human well-being is necessary to provide a sustainability path.

Key words: Environmental Kuznets Curve, Sustainable development, Human development, Genuine saving, Panel data
JEL: O15; Q01; Q56

1. Introduction

During last decades poor countries have faced a very important challenge, to get ahead of first stages of economic development and industrialisation process without damaging excessively their own environmental assets. A number of scholars and international organisations have suggested that poverty reduction should be one of the main policy actions in order to avoid environmental deterioration (WCED, 1987), while in the longer run, the surest way to improve environmental quality should be to become rich (Beckerman, 1992). Recently such a trade off between poverty and environmental quality has been criticised, suggesting that "win-win" policies in the development and environment spheres could be adopted, enhancing the so-called "sustainable development" level of the economic growth process (Munasinghe, 1999). High income levels could represent a

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condition which enables some countries to be first movers, but low income levels shouldn't be a barrier to achieve both lower levels of environmental damage and a higher degree of economic growth.

The examination of the environmental impacts produced by economic growth and the detection of a specific course in the various development stages has produced a series of empirical studies, published in the early 1990s. Their common output is the notion that environmental degradation worsens during the early stages of development and improves in the later ones, following an inverted *U*-shaped curve. On the basis of the seminal work of Simon Kuznets (1955) on the relationship between economic growth and income distribution, in the same venue Selden and Song (1994) coined for the first time the term Environmental Kuznets Curve (EKC). As for the classic Kuznets curve, in the case of the EKC the first stages of economic growth are characterised by increasing environmental degradation, while after a threshold level income per capita will continue to grow while environmental degradation will be reduced. Therefore, the relationship between economic growth and environmental quality doesn't embody necessarily a trade-off, where increasing income per capita could be exempted from any limitations related to natural resources or environmental degradation.

Explanations for the existence of an inverted *U*-shaped path have been considered both on the demand and the supply side, recovering the role of income elasticity for the demand of environmental quality, and the structural features of the productive system as the main drivers for enhancing environmental protection.

From the demand side, the most common explanation for the shape of an EKC is the notion that, as income grows, people achieve higher standards of living and care more for environmental quality. Therefore, after a threshold level of income, the willingness to pay for a clean environment rises by a greater proportion than income, due to high income elasticity of a luxury good such as environment. People become more concerned about depletion and degradation of the environment, hence exerting pressure on firms to use more pollution abating technologies and on decision makers to introduce environmental regulations.

Even if many EKC empirical findings have emphasised the role of income elasticity of environmental quality demand, in most cases the progress towards environmental protection has been mainly achieved due to institutional reforms and the existence of a democratic government, where the rule of law has played a basic role in order to translate public opinion pressure into a concerted program of pollution abatement (Munasinghe, 1995).

Considering the supply side, for the first time Grossman and Krueger (1995) have indicated three different channels through which economic growth affects the quality of environment: the scale effect, the composition (or structural effect), and the technique effect. Considering the scale effect, growing economic activity leads *ceteris paribus* to increased environmental damage, because a greater amount of natural resources is necessary for the production activities and higher polluting emissions are associated with increasing output. Secondly, structural changes can occur in the economy, leading to different environmental pressures. During the first stages of development (from agriculture to manufacture) environmental degradation tends to increase, whereas during the subsequent periods, the reverse occurs shifting from a heavy manufactured system to a service-oriented economy. This second channel is usually called composition effect. Thirdly, the various sectors of the economy may adopt less polluting technologies, either because of market-driven technological progress or government regulation: the introduction of environmentally-friendly techniques is labelled the technological effect. The specific nature of the abatement technologies with increasing returns to scale could constitute a further explanation of the EKC where high fixed initial investment costs for pollution abating techniques reduce the capacity of poor countries to implement pollution control policies (Andreoni and Levinson, 2001). The EKC hypothesis suggests that the negative impacts on environment linked to the scale effect tend to prevail in the initial stages of economic growth, but after a threshold level (of development) it should be outweighed by the positive impacts of the composition and technological effects. Consequently, there is no *a priori* reason to assume the relationship between income and environmental deterioration strictly monotonic: environmental quality may worsen with economic growth within some ranges of income, but improve over others.

The EKC has been analysed by many scholars both from theoretical and empirical perspectives, where a certain degree of scepticism has been recently related to the capacity of the curve to describe a sustainable growth path. At this purpose, some contributions have attempted to investigate the theoretical implications of a sustainable growth path and the possible linkages with an empirical EKC formulation. The role of sustainability, and not only environmental degradation, the implications related to technical progress, and the statistical techniques based on panel data and not pure cross-section analyses represent the main steps ahead recently made by the scientific community. The aim of this paper is therefore to overview such theoretical and empirical progress, trying to underline the possible relationships among all these new aspects. In order to do this, a Modified EKC (MEKC) has been modelled in order to consider a wider concept of development rather than pure economic growth, including well-being aspects and sustainability of the development process.

The rest of the paper is structured as follows. Section 2 describes theoretical investigations addressing the sustainability problem in the traditional economic growth models. Section 3 gives a broad overview of empirical studies, addressing the most recent enhancements including technical progress and using panel data analysis. Section 4 provides a general description of the methodological assumptions adopted in the MEKC. Section 5 shows empirical findings, while Section 6 deals with some concluding remarks.

2. Linking economic growth and environment from a theoretical perspective

The EKC literature consists of two distinct but related areas of research: an empirical strand – the majority – that looks for the econometric specification and a theoretical strand that models the interaction between environment and economic growth. The empirical models generally resort to ex-post theoretical justifications rather than ex-ante formal derivations and, at the same time, even if the results of theoretical models are broadly consistent with the empirical findings, they have rarely been confronted with the data. Theoretical contributions to the study of EKC can be divided into four major categories (Panayotou *et al*., 2000): i) optimal growth models; ii) models in which the environment is a factor of production; iii) endogenous growth models; and iv) other macroeconomic models of growth and the environment.

Optimal growth models are dynamic models in which the utility maximisation problem of the infinitely lived consumer is solved using the techniques of optimal control theory. Stock or flow pollution represents an argument of both the production function and the utility function of the representative consumer (Selden and Song, 1994; Stokey, 1998; Brock and Taylor, 2004b).

Differently, other models include environment as an argument of the production function, where both pollution and the stock of natural capital are arguments of production and utility functions. In these models property rights have a fundamental role in determining whether environmental degradation eventually declines with growth (Lopez, 1994; Chichilnisky, 1994).

In endogenous growth models production functions are characterised by increasing returns to scale and spill-over effects differently from the neoclassical specification (Bovenberg and Smulders, 1995; Stokey, 1998).

Other macroeconomic models refer to Diamond-type overlapping generation models, which add support to the results of the optimal growth models and generalise them (John and Pecchenino, 1994; Jones and Manuelli, 2000). In this residual category there are also included simple static models, like the one adopted by Stokey (1998) and the Robinson Crusoe model of Andreoni and Levinson (2001).

Brock and Taylor (2004a) analyse four theoretical models, in order to highlight the different ways environmental constraints can be met in the face of ongoing growth in per capita incomes.

The first one is an optimal growth model called the Green Solow model, where emission reductions arise from exogenous technological progress in both goods production and abatement. Even with the economy's abatement intensity fixed and no composition effects, the typical convergence properties of the neoclassical model, together with a standard natural regeneration function, trace out an EKC: the transition towards any sustainable growth path is characterised at first by a worsening of environmental quality and then by an improving, while approaching the balanced growth path.[1] Regarding technological progress, the model clearly shows how it has a very different environmental impact in goods production than in abatement: in the first case it produces a scale effect that raises emissions, in the second one creates a pure technique effect, driving emissions downwards. Therefore, the presence or absence of technological progress in abatement is a key factor in lowering emissions, supporting ongoing growth and predicting the costs of pollution control. This explanation for the EKC is entirely distinct from those offered in the literature, because it doesn't include composition effects, increasing intensity of pollution abatement, increasing returns to abatement, evolution of the political process and international trade.

According to this, Kelly (2003) adopts a stock externality model in an optimal growth framework; in this model, as incomes rise over the growth path, both the marginal benefits and the marginal costs of pollution control rise: if the former outweighs the latter at a given income, the emissions curve has a negative slope. The variation of pollution specific parameters - which determine marginal costs and benefits - determine specific emissions-income relationships: with this hypothesis, the emissions curve can be upward sloping or constant even when environmental quality is a normal good. For both stock and flow pollutants, the emissions curve may easily be non-monotonic if the trade-off between the change in marginal costs and benefits with respect to a change in capital varies over the growth path. The trade-off is sensitive to pollution specific parameters and in this sense the relationship between environmental quality and growth generally depends also on which measure of environmental quality is used (Lieb, 2002). For stock pollutants that depreciate quickly marginal benefits of emissions control are lower than marginal costs if the pollutant decays quickly: Kelly shows numerically that, since the marginal benefits of emissions control are smaller, the first kind of pollutants generate upward sloping curves.

The endogenous growth model adopted by Bovenberg and Smulders (1995) is very similar to the Green Solow model, because of the role of technological progress. Ongoing investments in the knowledge sector raise the productivity of pollution abatement, leading to a balanced growth path with a constant level of environmental quality; the "pollution augmenting technological progress" is

[1] This definition entails positive growth in order to avoid stagnation as a sustainable growth path. With ongoing income growth giving more marketable goods along the balanced growth path, it seems appropriate to require an improving environment since this provides more non market goods.

equivalent to the technological progress in the Green Solow model. The Green Solow model is also similar to Stokey's (1998) neoclassical model, differing for the role of technological progress. Stokey generates the EKC prediction through a change in pollution policy along the transition path, highlighting the role that abatement can play in improving the environment over time. In the Green Solow model reductions in pollution came about solely because of changes in technology and not because society allocated a greater share of its resources to pollution prevention. In order to have falling pollution levels with neoclassical assumptions on abatement function and no abatement specific technological progress, the intensity of abatement must rise indefinitely. Once abatement is modelled as an economic activity that uses scarce resources, increases in the intensity of abatement will reduce economic growth: rising abatement creates a technique effect by lowering emissions per unit output, but also lowers pollution by lowering the growth rate of output. Stokey offers a simple explanation for the empirical finding of an EKC, like Lopez (1994) and Copeland and Taylor (2004), showing how an income elastic demand for environmental protection can tighten environmental regulations up. This assumption on tastes, together with certain assumptions on abatement, succeeds in generating a first worsening and then improving environmental quality as growth proceeds. Adopting a Constant Relative Risk Aversion utility function, Stokey proves that emissions fall along the balanced growth path if and only if the elasticity of marginal utility with respect to consumption exceeds one. Only if consumers' valuation of consumption falls quickly, they are willing to take a smaller and smaller amount of national income as growth proceeds.

Stokey's explanation for the EKC is quite persuasive because it links rising income levels with a lower shadow cost of abatement and a higher opportunity cost of doing nothing, capturing the idea that policy responds positively to real income growth. Differently from the Green Solow model (technological progress in abatement) and from Stokey's model (intensified abatement), other forces could be responsible for the falling emissions to output ratio: one of them is represented by changes in the composition of output towards less energy intensive goods.

A model relying on this effect is represented by a source and sink formulation (Brock and Taylor, 2004a), that allows to examine how changes in the energy intensity of production help meet environmental constraints. Energy is introduced as an intermediate good, produced from an exhaustible natural resource, capital and labour and pollution as by-product of input use. Stokey has showed that increasing abatement creates drag on economic growth, whereas the source and sink model shows that a shift towards less energy intensive production lowers growth if it isn't accompanied by increases in capital and effective labour. While intensity of abatement is taken as constant and there is no technological progress in abatement, the economy is able to lower its emissions to output ratio over time by adopting an ever cleaner mix of production methods and composition of its inputs. The source and sink model highlights that the finiteness of natural resources implies a constraint on per capita income growth and in this way it links this approach to the earlier 1970s and 1980s literature focusing on resource exhaustion. Sustainability requires falling emissions and this constraint is most easily met if the economy makes a rapid transition away from natural resource inputs, reducing the energy and pollution intensity of output. Adopting this framework, abatement or composition shifts alone are unlikely to determine falling emissions: considering constraints from the source and sink side together makes clear that technological progress directly targeted to lowering abatement costs must play a key role in order to achieve the twin goals of positive ongoing growth and falling emission levels.

The Kindergarten Rule model (Brock and Taylor, 2003) emphasises the importance of technological progress in abatement and consider the optimising behaviour of a conventional infinitely lived representative agent. The model provides three important contributions. First, it shows how technological progress in abatement can hold compliance costs down in the face of ongoing growth. In contrast to the Green Solow model, there are ongoing costs from regulation but, as long as abatement is productive, it is possible to generate sustainable growth without rising quickly compliance costs. Second, in the Kindergarten Rule model the path for income and pollution differs across countries and this systematic difference leads to the Environmental Catch-up Hypothesis, relating income and pollution paths to countries initial income levels. Poor countries experience the greatest environmental degradation at their peak, but regulation allows a convergence of environmental quality across both rich and poor. In addition, knowledge spill-overs eliminate diminishing returns to abatement and, as a consequence, learning by doing reduces abatement costs. The introduction of learning by doing, combined with abatement efforts, generates a first worsening and then improving environment; in a static setting, learning by doing is identical to increasing returns. Andreoni and Levinson (1998), laying out a simple and straight-forward static model of the micro-foundation of the pollution income relationship, show that the optimal pollution income-curve is inverse *U*-shaped if and only if the abatement technology has increasing returns of scale. Therefore EKC doesn't depend on tastes changing as income grows; rather it's connected to the technological link between consumption and its undesirable by-product (pollution). Abatement expenditures reduce the pollution generated by consumption and if abatement has increasing returns of scale the target of more consumption with less pollution, demanded by high-income individuals, can be more easily achieved.

Jones and Manuelli (1995) use an overlapping generations model in which the choices of firms among different techniques are influenced not only by price, but also by restrictions on use imposed by the government. To model this aspect of firm decision making, they assume that the government sets technique-specific taxes with the aim of controlling pollution. Public policy is endogenously determined and two settings of majority voting on environmental protection: voting over effluent charges or over direct regulation of technology, choosing minimum standards. When voting is over effluent charges, the time path of pollution is an inverted U, followed by a sustained increase similar to that empirically observed. If, instead, individuals vote directly over the "dirtiest" available technology, the level of pollution monotonically increases to a bound level as consumption grows. In both of these cases, the assumption of environment as a luxury good is a fundamental element: if preferences are homothetic, pollution will grow without bound. The analysis suggests that endogenous policy choices should be taken seriously as a key source of heterogeneity when studying cross-country differences in economic performance. The model is consistent with different policies driving differences in per capita income across countries and it also suggests a bi-directional causality: differences in levels of income across countries give rise to differences in selected policies, implying differences in growth rates.

3. The empirics of the EKC: a literature review

As initially suggested by Grossman and Krueger (1995), the relationship between pollution and growth has been estimated using reduced-form equations that relate the level of pollution to a flexible function of income per capita and to other covariates.[2] The classical reduced functional form representing the EKC is given by equation [1]:

$$E_i = \beta_0 + \beta_1 X_i + \beta_2 X_i^2 + \beta_3 X_i^3 + \beta_4 Z_i + e_i \qquad [1]$$

where E_i represents the general level of environmental stress, X_i the income per capita and Z_i other covariates. The inverted *U*-shaped curve deriving from such a formula requires β_1 to be positive, β_2 negative and β_3 positive.[3] Some contributions estimate the EKC using a dynamic specification, where lagged values of income per capita have been introduced in order to understand the medium/long-run pattern (Bradford *et al.*, 2005; Coondoo and Dinda, 2002; Grossman and Krueger, 1995; Perman and Stern, 2003).

Many contributions have empirically tested the existence of an EKC using cross-country

[2] The advantage of a reduced-form approach addressed by Grossman and Krueger (1995) is that the reduced-form equation gives the net effect of a nation's income on pollution. Otherwise, if the structural equations relating environmental regulations, technology, and industrial composition were estimated, "one would need to solve back to find the net effect of income changes on pollution, and confidence in the implied estimates would depend upon the precision and potential biases of the estimates at every stage" (p. 359-360).

[3] The cubic term derives from the empirical evidence found by Grossman and Krueger (1995), where the relationship between income and emissions becomes positive again for certain types of pollution (SO_x) for higher income level.

relationships (among the others, Grossman and Krueger, 1995; Shafik, 1994; Stern *et al.*, 1996), time series analyses for specific countries (Egli, 2002; Vincent, 1997), or panel data for subsets of countries and time series with different length (Dijkgraaf and Vollebergh 1998, 2001; de Bruyn *et al.*, 1998; Wagner and Müller-Fürstenberger, 2004; Torras and Boyce, 1998; Panayotou *et al.*, 2000).

The majority of EKC study has examined air pollution: firstly carbon dioxide emissions, whose data are available for a wide range of countries and long time series; secondly sulphur dioxide, oxides of nitrogen, suspended particulate matter and carbon monoxide. Water pollutants have also been studied, as coliform, biological and chemical oxygen demand in river, and different environmental problems, as deforestation and endangered species. Therefore, most of EKC studies have investigated flow pollutants, and the analysis has rarely been devoted to stock pollutants or natural resources.

A critical examination of the EKC literature highlights that the estimated relationship suffers from a number of theoretical and empirical criticisms about: i) the existence of omitted variables; ii) the reduced functional form; iii) the role of technical progress; iv) the choice of the econometric specification; v) the non univocal results for alternative formulations; vi) problems related to measurement issues both for the dependent and the independent variables.[4]

i) In order to reduce problems affecting the robustness of the econometric specifications linked to the existence of omitted variables, further contributions have introduced other covariates, modelling the effects linked to trade openness, globalisation and the manufacturing sector (Cole, 2004; Hettige *et al.*, 2000; Tisdell, 2001) or linked to well-being aspects such as income distribution, education and health (Gangadharan and Valenzuela, 2001; Hill and Magnani, 2002; Magnani, 2000). Finally, many contributions try to shed some light on possible failures in the theoretical interpretation of the EKC (Arrow *et al.*, 1995; Munasinghe, 1999; Stern and Common, 2001). Income can difficultly be considered the only exogenous factor in the determination of environmental quality: only if other variables are endogenously expressed through income, or correlated with it, they can be omitted; otherwise it's necessary to make explicit their contribution. The choice of independent variables influences stochastic error, determining the explanatory power of the regression. An explanatory power decreasing over time indicates the weakening of the link between income and environmental quality and an increasing importance of omitted variables (Hill and Magnani, 2002).

ii) It has rarely been considered that variables involved in the estimation of environment-GDP relation could be simultaneous: the EKC hypothesis derives from a model of economy in which the state of the environment hasn't any feedback on economic growth's process. The reduced form

[4] For a comprehensive literature review of the EKC, see Dasgupta *et al*. (2002) and Dinda (2004).

rather than the structural form equations have been used in most of the EKC studies, in which income is assumed to be an exogenous variable: clearly, this not account for irreversibility and sustainability problems. Moreover, reduced forms do not account for causal mechanisms: structural forms may warrant exploration because some interdependence is probable, both referring to independent variables and to different environmental indicators.

iii) Regarding the supply side of economic growth, the combined action of three effects is fundamental in order to obtain an EKC: scale, composition and technological effect. In particular, technological progress leads to greater efficiency in the use of energy and materials; thus, a given amount of goods can be produced with successively reduced burdens on natural resources and environment. New technologies improve productivity but also create potential dangers to the society such as new hazardous wastes, risk and other human problems. These externalities are unknown in the early phase of diffusion of technology, while in later stages regulation becomes warranted to address it: in this sense an inverted-*U* shape can be observed with reference to each technology. Then, over a certain period during which income grows, one pollutant may decline but another may rise due to adoption of a new technology (Dinda, 2004).

Technological progress is of course a fundamental variable in determining an inverted U relation but, while on the theoretical side its rule has been highlighted on empirical side it's difficult to find an effective measurement. Very often technological progress has been modelled with a time trend (Shafik, 1994; Holtz-Eakin and Selden, 1995), related to every individual country, in other cases as a global common effect, reflecting shared technological progress (Stern, 2002). Unruh and Moomaw (1999), with a non-parametric model, demonstrate that access to technology and technological progress can help in reacting to temporal shocks that generate EKC paths. Technological progress is certainly a structural parameter determinant for heterogeneity between countries and a key factor to be considered in the issues of irreversibility. Any attempt to derive policy implications from EKC requires some understanding of the economic and political forces behind the empirical results and in particular, to the extent that an EKC is observed, it is important to distinguish whether it is a natural consequence of structural changes in the economy or it is a result of a planned and concerted effort to reduce pollution emissions, carried out through government regulations and enhancement of pollution abating technologies.

iv) Concerning the statistical methodology, first contributions on EKC hypothesis have generally employed cross-section data, while at present most of the studies uses panel data, examining individual countries over time and using, as econometric techniques, variants of traditional regression methods. The simplest regression formulation assumes constant coefficients across countries, implying that every country follow the same EKC; with panel data it is possible to free up this restriction and allow the regression intercept to vary across countries. In particular, using the fixed effects approach, it is implicitly assumed that the environment-GDP relationship varies across countries in a restricted way: countries have different intercepts but they have the same turning point where environmental degradation starts declining, where the amount of environmental degradation at this point can differ among countries. This assumption of a low degree of heterogeneity is probably not enough, given the variety of social, economic, political and biophysical factors affecting environmental quality from one country to another. Hence, some studies apply a random coefficients model, allowing for more cross-country heterogeneity in the shape of the environment-GDP relationship. This is not to say that homogeneity doesn't exist, but the assumption of a common structure within a country over time is probably more reasonable than that of a common structure across countries. Indeed, the physical and social features, that are what determines each country's distinctive growth environmental outcomes, remain more or less constant over time (Koop and Tole, 1999).

v) Another problematic feature of the EKC hypothesis is represented by the non-univocal results, which can be conflicting choosing a cross-country or a panel approach: EKC hypothesis can be rejected using the first one, and accepted using the second one (Selden and Song, 1994). Moreover, using different econometric techniques, a differentiation regarding to the value of the turning point can emerge. The non-univocity of regression output can be led back to the lack of homogeneity between the examined countries or to others aspects, represented by data availability and the specific pollutant examined. Hence, in absence of a single environment indicator, the estimated shape of the environment-income relationship and its possible turning point strictly depend on the pollutant considered.

vi) Concerning measurement issues, it should be given attention to the distinction between conventional income per capita, as an indicator of growth, and other measures, more complex, which might better capture the concept of sustainable development. The economic growth is usually measured through the employment of Gross Domestic Product (GDP); this choice limits the alternative interpretations and the potentialities of results, because GDP is often highly correlated with omitted variables (Kaufmann *et al.*, 1998). Beside of the absence of distinction between correlation and causality, there is another problem tied to the adequacy of the GDP in representing sustainability and well-being. Hill and Magnani (2002) suggest the possibility to replace GDP with more inclusive measures of well-being, like Net Domestic Product (NDP) or Genuine Progress Indicator (GPI), Index of Sustainable Economic Welfare (ISEW) and Human Development Index (HDI).

Different options of measurement are mainly directed to entail issues of environmental sustainability into the analysis of income-pollution relation. Munasinghe (1999) employs Environmentally Adjusted Net Domestic Product (EDP), calculated subtracting to the Net Domestic Product the product between the net loss of natural capital, measured in physical units, and its value. The corresponding EKC shows a steeper upward sloping and can be replaced from a reversed-C relation if, beyond a threshold level of environmental degradation, EDP begins to decline. In this case, it should be considered that EDP doesn't indicate if the saving rate is high enough to guarantee a future income level equal to the current one. Computing an indicator like the Genuine Saving (GS) provided by the World Bank (Hamilton, 2000), it is possible to have a real saving rate net from the amounts needed to cover the depletion of natural resources and the economic value of social cost linked to pollution damage. While trends in national income per capita (using traditional or green measures) may express the effect of economic growth in the short run, measuring trends in real savings per capita could give a much clearer picture of the influence of wealth creation on environmental quality.

4. Methodology and data description

The various critiques to the initial EKC formulation have stimulated a large debate around alternative representations of the relationship between economic growth and environment. A part from the criticisms moved to the econometric specification, a more sustainability oriented EKC seems to be a new research line which could allow linking the new theoretical formulations with a more accurate specification of the empirical findings.

Jha and Murthy (2003) represent a relevant contribution, not only characterised by sustainability implications but also useful in order to solve the problem of non-univocity of results: they examine the EKC hypothesis using HDI as a broader measure of economic development and the Environmental Degradation Index (EDI) as a global indicator of environmental quality[5]. The 174 countries examined are divided in three classes of HDI (high, intermediate and low, respectively with HDI>0.8, 0.8<HDI<0.5, HDI<0.5) and the regression output indicates a positive correlation between EDI and HDI for countries with high HDI, a negative relation for countries with low HDI and weakly negative relation for the intermediate class. These findings confirm an inverted *U*-shaped relationship, where the level of environmental degradation is strictly dependent on the development stage. In the same venue, Costantini and Monni (2006) examine the EKC hypothesis through a similar formulation, using HDI as a development indicator and the Genuine Saving (GS)

[5] EDI is determined by a composite index formed by different factors representative of economic growth, everyone with a specific weight; this suggests the inadequacy of an approach that isolates a single index of environmental quality in order to investigate the relationship with economic growth.

as a sustainability measure. GS is observed to increase as long as HDI augments and almost null GS variation rates are connected to countries with low and medium-low levels of HDI. In this case, the threshold level of un-sustainability is associated to a low-medium level of HDI (around 0.60), while threshold levels for classical EKCs are well above this value, hence confirming the so-called "tunnelling through the curve" hypothesis formulated by Munasinghe (1999).[6]

The aim of this paper is to collect such recent suggestions, trying to make some steps ahead: i) to model a modified EKC (MEKC) in a panel context; ii) to partially solve the question of reduced form, including an endogenous covariate represented by the quality of institutions; iii) to represent the role of technical progress.

In order to represent a more general framework geared towards sustainable development, the dependent variable defined as environmental degradation in the standard EKC is replaced by a macroeconomic sustainability indicator based on the Genuine Saving (GS) index provided by the World Bank in the World Development Report (World Bank, various years). GS is formally expressed in equation [2]:

$$GS = \dot{K} - (F_R - f_R)(R - g) - b(e - d) \qquad [2]$$

where $\dot{K}$ represents economic capital formation while other terms are adjustments for consumption and degradation of natural capital. In particular, the economic value of natural resources consumption (resources extracted R minus natural growth rate g for renewables) is given by the resource rental rate (F_R) net of the marginal cost of extraction (f_R), while pollution (emissions e minus natural dissipation rate d) is evaluated by the marginal cost of abatement b.

Separate economic values for some types of natural resources exploited at national level such as energy and mineral resources, forests and marginal economic damage linked to CO_2 emissions (i.e., the cost of climate change) are then available.[7] GS is based on the assumption of perfect resource substitutability and it could therefore be interpreted as a limit value of sustainability.

The income factor of the EKC is replaced with a more comprehensive measure of development, adopting the theoretical framework developed by the UNDP, the so-called human development paradigm, based on the capability approach defined in the seminal work of Amartya Sen (1979).

The Human Development Index (HDI) in the UNDP standard methodology includes three dimensions for human well-being, representing the basic capabilities for individuals in order to

[6] Other attempts to analyse the relationships between economic growth/development and sustainability can be found in Dasgupta and Maler (2001) and in Neumayer (2001).

[7] Energy and mineral resources considered in the WDR are oil, natural gas, coal, bauxite, copper, lead, iron, nickel, phosphates, tin, zinc, gold, silver. For methodological and empirical explanation of effective components of Genuine Saving index, see Hamilton and Clemens (1999).

achieve decent standards of living. The following three dimensions are included in the HDI: (i) a long and healthy life; (ii) access to knowledge; (iii) a decent standard of living.[8] In order to represent such dimensions some basic indicators are collected, as the life expectancy at birth, the literacy rate, the gross enrolment ratio, as well as the income per capita.

Considering that the GS is computed in economic terms, the income dimension in the classic HDI could bring to multi-collinearity and biased estimation. Therefore, a modified HDI (HDIM) is built as a simple average of the first two dimensions, the expectancy of life and the education index respectively, where both factors are normalised with a maximum value (85 years for expectancy of life and 100% for literacy and enrolment ratios) and a minimum value (respectively 25 years and 0%).

The exact formulation of the HDIM is the following:

$$\text{HDIM} = 1/2\,(\text{Expectancy of life Index} + \text{Education Index}) \qquad [3]$$

$$\text{Expectancy of life Index} = \frac{x_1 - 25}{85 - 25} \qquad [4]$$

$$\text{Education Index} = \frac{2}{3}\underbrace{\left[\frac{x_2 - 0}{100 - 0}\right]}_{\textit{Literacy Index}} + \frac{1}{3}\underbrace{\left[\frac{1}{3}\sum\frac{x_{3i} - 0}{100 - 0}\right]}_{\textit{Gross enrolment ratio}} \qquad [5]$$

where

x_1 = Expectancy of life (number of years)

x_2 = Adult literacy rate (percentage of literate population with age > 15 years)

x_{3i} = Primary, secondary and tertiary gross enrolment ratio (enrolment in a specific level of education, regardless of age, expressed as a percentage of the official school-age population corresponding to the same level of education in give school-year).[9]

Differently from previous studies, in this analytical framework we have adopted a stronger sustainability criterion, considering only the components of GS related to depletion and degradation of natural capital. Therefore, an adjusted GS (AGS) is built upon the GS methodology excluding the factor explaining manufactured capital accumulation ($\dot{K}$).

The value added of such analysis is the presence of depletion and degradation value of natural resources contained in the AGS index compared with the simple pollutant emissions considered in a classical EKC model. In addition, using HDIM and not a simple income measure allows broader considerations to be made on the sustainability of the development path or if future generations

[8] For a full description of the methodological issues about the HDI, see the Technical Notes in the Appendix of the Human Development Reports (UNDP, various years).

[9] UNESCO definition, Education and Literacy Indicators, 2001.

could enjoy the same well-being level (and not only income). In line with classic EKC, the inclusion of other control variables such as trade flows and manufactures as the share of value added even allows us to analyse the effects of economic globalisation on sustainable development.

Following recent contributions (Costantini and Monni, 2006; Gandaran and Valenzuela, 2000; Jha and Murthy, 2003), an alternative formulation has been implemented in order to reduce the problems highlighted for the EKC about the reduced form, trying to model the influence of institutions modelled as an endogenous variable.[10]

In this paper, we have adopted the definition of institutional quality provided by Kaufman *et al.* (2003), where six different characteristics describe this aspect: Rule of Law (RL), Political Instability (PI), Government Effectiveness (GE), Control of Corruption (CC), Regulatory Framework (RF), and Property Rights and Rule-based Governance (PR). There exist many alternative indicators provided by international agencies measuring in different ways the quality of institutions and governance issues, but unfortunately it is almost always the case that these indicators don't cover a wide sample of countries. It is the case of the Corruption Perspectives Index provided by Transparency International and used by Dasgupta *et al*. (2006) for similar purposes in an EKC context. This index is used for representing the World Bank's CPIAE (Country Policy and Institutional Assessment for Environment), which rates countries from 1 to 6 in ascending order of effectiveness in environmental governance. The authors affirm that CPIAE and TICPI are highly correlated; hence TICPI has been used because of its larger dataset. Considering that dataset for Rule of Law is much wider than TICPI, we have decided to maintain RL as the institutional variable in order to have as many observations as possible. In the same venue, Farzin and Bond (2005) have investigated the role of a democratic government in enhancing environmental protection, and their empirical findings reinforce the hypothesis that institutions addressing for the preferences of the majority of citizens are more oriented towards environmental regulation.

In our empirical investigation the quality of institutions has been tested firstly as an exogenous, and later on as an endogenous variable, in a panel dataset instead of a pure cross-section context. The first formulation has been carried in a panel context with three separate temporal observations (1990, 1995, and 2000) in order to compare results for alternative pollutants (CO_2, NO_X, and SO_X) and AGS.[11] Moreover, extending the analysis to a longer time period (1996-2004) allows reinforcing the robustness of the results using a MEKC instead of the traditional EKC.

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[10] Costantini and Monni (2006) test the hypothesis of a system of equations representing the possible interrelations between the EKC and the so-called Resource Curse Hypothesis, trying to highlight which variables play a key role in a long-run sustainable development path, in the presence of large exhaustible resources stocks.

[11] The choice of the years for observations is closely related to the data availability for NO_X and SO_X emissions.

Finally, last dimension here considered is technical progress, in order to module the theoretical issues recently analysed in many contributions (Brock and Taylor, 2004b; Stokey, 1998; Andreoni and Levinson, 2001). Considering the difficulty of finding indices of technical progress available for a wide range of countries and for more than one year, we have modelled it adopting two different points of view. In the first analysis the role of production of technologies has been introduced, represented by the number of patents from residents expressed as percentage of GDP (PAT), but as we will see the coefficient related to this index is very low. Therefore, we have adopted the methodology developed in Archibugi and Coco (2004) where an index of "technological capabilities" has been built, representing four different aspects of technical progress: (i) the creation of technology; (ii) the technological infrastructures; (iii) the development of human skills; (iv) the import technology. Considering our analytical framework, in order to reach a sustainable development path both the creation of technology (patents) and the adoption and diffusion of clean technologies are important. Therefore, the concept of technological capabilities perfectly fits our analysis. Considering that human skills are widely represented by the human development dimensions, we have built a new technological index based only on two out the four components proposed by Archibugi and Coco (2004). In order to represent the technological infrastructures we have accounted for internet and telephone penetration (number of internet, fixed and mobile telephone lines per 1.000 persons), while for import technology we have considered the inward Foreign Direct Investment (FDI) flows as percentage of GDP. The final formulation of this index (named ARCO as the original one) is as follows:

$$ARCO = \frac{1}{2}\left\{ \underbrace{\left[\frac{1}{2}\left(\frac{ln(TEL_i)}{ln(max_{TEL})} + \frac{INTERNET_i}{max_{INTERNET}} \right) \right]}_{technological\ \ infrastructures} + \underbrace{\left(\frac{FDI_i}{max_{FDI}} \right)}_{import\ technology} \right\} \qquad [6]$$

As we can see, the formulation of the ARCO index is based on the same methodology adopted for the HDI, where the observed values are normalised by a minimum and maximum value. In this case the minimum value is always equal to zero, while the maximum value has been taken in the whole time period/countries sample considered in this work. This formulation gives the possibility to account for temporal changes at country level, as well as the methodology adopted by UNDP for the HDI. Following the UNDP methodology, the component related to telephone users has been considered in a logarithm form, creating "a threshold above which the technological capacity of a country is no longer enriched by the use of telephones" (Archibugi and Coco, 2004, p. 635).

We have not considered the electricity consumption within the technological infrastructures because there are other energy related variables in our model, while for the import technology we have not considered the technology licensing payments and import of capital goods in order to maintain a large sample of countries.[12]

5. Empirical results

5.1 First results from single equations

A first comparative analysis between classic EKC and a MEKC has been described using alternative pollutants and AGS for three years, 1990, 1995, and 2000.

Following the large body of literature, some conditioning variables are added to the model in order to better describe the relationships between economic growth (development) and environment (sustainability). The share of value added from manufacturing sector should help understanding the role of the industrialisation process (composition effect), where an economy strongly based on heavy industries should have higher polluting emissions comparing to economic systems based on agriculture (first development stage) or services (advanced development stage) (Hettige *et al*., 2000).

The role of structural adjustments claimed by standard EKC literature is not well represented by the share of manufacture value added on total value added as soon as we introduce other explanatory variables as the energy intensity, the role of population density, and the quality of institutions. These results are probably related to the widely known problems of omitted variables in the previous EKC studies.

As in de Bruyn *et al*. (1998) and Suri and Chapman (1998), the role of energy intensity has been accounted, represented by the energy consumption as percentage of GDP (ENE). Looking at our first results, energy use plays a major role especially for CO_2 and SO_X (Tables 1 and 2), both pollutant emissions typically related to the production (and consumption) of energy products. At the same time, the estimates for energy consumption related to AGS (Table 4) are not statistically significant, probably because the components of AGS related to natural resources depletion mitigate the relationship between energy intensity and CO_2.

Another important issue is related to the role of international trade and globalisation, usually described using the percentage of imports plus exports on total GDP (Tisdell, 2001). In our work, imports (IMP) and exports (EXP) as percentage of GDP are included as two separate variables, because import and export flows can drive to opposite effects in terms of environmental degradation (Agras and Chapman, 1999; Cole, 2004). For SO_X and NO_X both imports and exports are not

[12] For a full description of the indices related to technological capabilities and the ARCO methodology see Archibugi and Coco (2004).

statistically relevant (Tables 2 and 3), while for CO_2 and AGS the two variables show the expected signs (Tables 1 and 4), where higher imports correspond to lesser production (and lesser pollution) while higher exports correspond to the opposite phenomenon, with increasing production and pollution.

Considering the MEKC calculated for AGS, not only imports and exports have the expected signs and they are both statistically significant within the all three alternative models, but the coefficients are higher than the other three EKCs calculated on alternative pollutants. This last result could be partially explained considering that the AGS partially depends on the exploitation of natural resources. In this case the role of primary resources exports (fuels and minerals) could play a major role, because in most of the oil exporting countries, fuel exports are the largest part of total balance of payments. In this sense, a specific dummy for main oil exporting countries has been introduced (OIL) in the MEKC, in order to reduce possible bias.[13]

The direct effect of population apart from GDP per capita has been tested including the population density (Kauffman et al., 1998; Selden and Song, 1994; Cropper and Griffiths, 1994), and the coefficients for all the four alternative models are generally statistically significant but they represent a minimum effect in terms of environmental degradation/sustainability.

Considering last available contributions on EKC, in some cases there emerges that *ceteris paribus* better institutions could help managing environmental degradation as well as sustainable development. For instance, Dasgupta *et al*. (2006) adopted a measure of corruption perspectives in order to proxy the stringency of the environmental regulation, founding that better regulation should help to reduce environmental vulnerability at urban level. In the same venue, Farzin and Bond (2005) affirm that the quality of institutions (i.e., the level of democracy) could be interpreted as a proxy of the willingness to pay of a society to protect environmental resources.

Considering the alternative formulation of the MEKC where the dependent variable represents a sustainability measure, the inclusion of institutions within the explanatory variables seems to be a natural extension of our study.

>> INSERT Table 1 – EKC for CO_2 (years 1990-1995-2000) <<

>> INSERT Table 2 – EKC for SO_X (years 1990-1995-2000) <<

>> INSERT Table 3 – EKC for NO_X (years 1990-1995-2000) <<

>> INSERT Table 4 – EKC for AGS (years 1990-1995-2000) <<

[13] In order to check for the robustness of the MEKC specification, alternative variables have been tested. First, AGS has been replaced with the standard GS (including capital accumulation term) and results remain consistent and robust. The same equation for MEKC has been estimated as well using classic GDP per capita instead of HDIM, but the results are quite similar both for significance and consistency, therefore while using HDIM does not change significantly the estimation, on the contrary it allows underlining a development path oriented towards capabilities and not only confined within the utilitarian approach. Results are not reported in the paper but they are available from authors upon request.

In contrast with previous EKC studies addressing for the role of institutions, looking at our results the quality of institutions seems to negatively affect the environmental quality/sustainability with coefficient quite high and statistically consistent both for CO_2 and AGS. Running the same MEKC equation separately for developing and developed countries the coefficient for RL still remains positive in both cases, but in the case of developing countries it is quite higher than for the MECK calculated on developed countries sample.[14] These results confirm the role of institutions in the economic growth/development path, or in other words countries characterised by good institutions would face faster economic growth/development process, and consequently higher environmental degradation in the first stages of development. The differences in the coefficients between developing and developed countries reinforce this consideration, where countries in the first stages of development would face greater degradation. It is hardly surprising if we consider the meaning of Rule of Law as an index of security in the investment markets for firms (the higher the index the lower the risk of bureaucratic barriers to profit maximisation). A more appropriate measure of institutional quality in our context should be the environmental stringency and regulation, but unfortunately there are few available data for developing countries to build a panel dataset.

Finally, last dimension here considered is technical progress, and in this case it is a difficult task to find indices available for a wide range of countries and for more than one year. In this first analysis the number of patents from residents has been introduced (PAT), but the coefficient related to this index is very low. At this purpose, the alternative approach developed by Archibugi and Coco (2004) has been tested to model technical progress (see par. 5.2).

The relationships emerged for SO_X and NO_X are clearly not robust in a panel context with a small T, therefore in the following sections we will concentrate only on EKC modelled for CO_2 and AGS.

In this analysis, the cubic form of the EKC is valid and robust for CO_2, but it is not statistically significant for AGS; hence the MEKC will assume the simple quadratic form. This result is hardly surprising if we consider the different components of the AGS measure. For CO_2 the cubic form is associated to the increasing environmental efficiency in the productive sector – the technological effect – and the shift from heavy industries to services – the structural effect – which determine the descending part of the curve, and to the increasing demand for energy products as income raises further (the second ascending part of the curve). In the case of the AGS, this second effect does not occur because the sectoral shift from manufactures to services is accompanied by another similar effect related to the reduction of resources extraction, producing a general effect greater than the increasing in CO_2 emissions due to the increasing demand for energy products.

The equations for the three pollutants and AGS have been performed using both fixed effects (FE)

[14] In the sample of developed countries the minimum value of the confidence interval is negative, reinforcing our considerations (results are not reported in the text but they are available from authors upon request).

and random coefficients (RE) models. FE models are always preferred to the RE models as the Lagrange Multiplier (LM) tests for RE show in Tables 1, 2, 3 and 4.[15]

For all the pollutants and for AGS we have tested the hypothesis of the existence of an EKC, performing an *F*-statistics on the hypothesis that β_1 (linear term) and β_2 (quadratic term) are jointly equal to zero, as suggested by Koop and Tole (1999). For all the dependent variables except for NO_X, the *F*-tests reject the null hypothesis of coefficients jointly equal to zero; hence an EKC for CO_2, SO_X and AGS is a valid model. In any case, it is worth noting that results from EKC applied to different environmental degradation indices are non univocal, and some caution is necessary when policy implications from EKC were drawn.

As we have already mentioned, the quality of institutions is quite often modelled as an endogenous variable, with a number of different instruments such as initial level of development, the role of natural resources endowment or the effects related to colonialism (Isham *et al.*, 2003; Sala-i-Martin and Subramanian, 2003). In our exercise, modelling the EKC with an endogenous variable as the quality of institutions allows understanding those mechanisms influencing economic performances, and environmental degradation, which are not caught by the reduced form of the standard EKC (Bradford *et al.*, 2005). In this sense, it is possible to not include other covariates in the EKC model, and at the same time it is possible to understand how other conditions such as initial level of development (initial GDP per capita or initial HDIM), the role of investments and the macroeconomic stability (given by the inflation rate) influence the quality of the institutions, and indirectly the environmental quality. For instance, Brock and Taylor (2004a) put the evidence on the role of the "Environmental Catch-up Hypothesis" where difference in pollution levels highly depends on the initial level of GDP per capita.

Analysing the specific results for the instrumented quality of institutions, the chosen variable (RL) highly depends on the initial value of HDIM, the changes in HDIM occurred during the period, and secondly on the initial income level, while investments and macroeconomic stability have much less influence.

Instrumenting RL in the MEKC and in the EKC for CO_2 doesn't imply significant variability in all the coefficients. Coefficients for RL associated to MEKC remain higher than in the case of CO_2 emissions. What strongly emerged is that looking at the Hausman test for endogeneity, there emerges both for AGS and CO_2 that the instrumental variables (IV) estimates are more appropriate than the simple model (Table 5).[16]

It is worth noting that in this specific panel setting results from separate estimates are not so far

[15] Hausman tests for RE have been performed confirming results from LM tests.
[16] The Hausman test has been performed using STATA, where the tested hypothesis H_0 is that difference in coefficients from the two alternative specifications is not systematic. We reject the null hypothesis in both cases, for CO_2 and AGS.

from results in IV models, and this is probably related to the temporal structure of the panel with only three temporal dimensions. Therefore, in the following section we will investigate the feasibility of the model applied to longer time series.

>> INSERT Table 5 – EKC for CO_2 and AGS, IV (years 1990-1995-2000) <<

5.2 Longer time period and simultaneous equations

Considering a longer time period where data for both CO_2 and AGS are available, and homogeneous information for institutional quality are available as well, it is possible to build a pooled model with a larger number of (*T*) temporal observations. Therefore, the time series for MEKC refers to 1996-2004, while for EKC the time period is shorter (1996-2002). Accounting for so recent years gives us the possibility to analyse the aspect related to technical progress from another point of view. We have seen that an indicator such as the number of patents registered by residents as ratio of GDP has not a great significance in terms of increasing or declining environmental degradation or sustainability. This result in our opinion is mainly related to the indicator itself, which is available only for developed countries and few more advanced developing countries. Considering that in this paper we have assumed a partially different point of view, where a wider concept of development replaces the pure economic growth accounting, we can also maintain this perspective in the analysis of technological progress. Therefore, we have included the technical capabilities index (ARCO) built on the basis of methodology developed by Archibugi and Coco (2004), in particular addressing for technological infrastructures (TECHINF) and import technology (TECHIMP).

>> INSERT Table 6 – Unit root tests for EKC and MEKC (1990-2004) <<

The time series here adopted is a quite short one, because for RL there are available data only for the period 1996-2004. In any case, in order to exclude possible biases related to non stationarity of time series we have performed unit root tests in a panel context for CO_2, AGS, GDP and HDIM (where for CO_2 the period is 1990-2002, while for AGS, GDP and HDIM is 1990-2004). Results reported in Table 6 clearly show that all the series but HDIM are stationary, while even HDIM becomes stationary when eliminating the temporal trend.

In any case, it must be noticed that for panels with *T* small the asymptotic distributions of panel unit root and cointegration tests provide poor approximations to the small sample distribution (Wagner and Müller-Fürstenberger, 2004; Galeotti *et al.*, 2006). Considering that the effective period is rather short and the unit root tests are favourable to stationary series, the model can be performed without further investigation on cointegration. In any case we have tried to reduce possible auto-correlation of HDIM introducing the value of HDIM with one temporal lag. Results are reported in Table 7, showing that the coefficient associated to HDIM(-1) is not statistically consistent, excluding problems of non-stationary series.

Looking deeply into the results, using longer time series does not change significantly our first results, where an EKC for CO_2 and for AGS is confirmed. What strongly emerges from this new panel setting is related to the role of institutional quality and to interesting results due the ARCO index.

The role of institutions remains unchanged for the MEKC, where better institutions are associated with unsustainable development paths. This result is fully explained by the presence of a large number of developing countries in our sample. If we consider not the AGS but the GS measure (including capital accumulation), the coefficient for RL is still positive but rather smaller than for AGS. If we consider alternative country samples, as for instance developing and developed countries, this result is fully explained. While for developing countries the coefficient for RL is positive, running the model for developed countries gives us a negative value for coefficient related to RL. If we look at the CO_2 emission, the model with endogenous RL gives a negative coefficient both for developing and developed countries, and this is in line with our expectation that better institutions are related with more stringent environmental regulations.[17]

Another difference relates to the divergence of coefficients for RL between single equation and IV using different panel settings. While in the panel using three separate years (1990-1995-2000) the estimates are quite similar, the MEKC with IV for RL in the 1996-2004 period gives results quite different from the single equation model. Furthermore, there is a wider difference between coefficients for RL in AGS and CO_2, reinforcing our first findings where the different components of AGS could be influenced differently by institutions. As we have seen, one of the most effective instruments for RL is changes in HDI level (HDIMCH), meaning that higher efforts to accumulate human capital and more generally to guarantee more access to capabilities to individuals correspond to a greater consumption of natural resources, especially in the first stages of development where an economy could be typically resource-intensive.[18] In this sense, coefficients associated to imports

[17] In order to test the robustness of results related to the role of institutions, we have run the same formulation for the period 1996-2004 using the other governance indicators provided by Kaufmann *et al*. (2003). The coefficients for these other indices are often positive (like RL) but not statistically significant. In the case of Political Instability the sign is negative and coefficient is robust, but it is close to zero. Running equations for developed and developing countries reveals the same trend as for RL, where coefficients are negative for developed countries and positive for developing countries. Results are available from the authors upon request.

[18] Following Ranis et al. (2000) HDIMCH has been formulated as the reduction of the HDIM level from the target level (that is equal to 1). Therefore, countries with higher initial level of HDIM are penalised in terms of HDIMCH performances. This means that the poorest countries are generally those in which the higher HDIMCH occurs, and this explains the increasing coefficient of RL in IV MEKC.

and exports are higher for AGS than for CO_2 and this is perfectly in line with our interpretations. An economy based on resource extraction, typically obtain a great part of its revenues from exports of primary resources. Therefore an increase in export flows would be immediately transformed into greater resource depletion (AGS increased) while the contrary applies for import flows.

For CO_2, running separate models for developed and developing countries there emerges a significant difference in results. In fact, for developed countries the coefficient associated to RL in single equation model is significant and negative, while for developing countries the coefficient is slightly positive and still significant. In the case of the IV model, the coefficient for RL is positive but not statistically significant. In the model with IV, the coefficient for RL is negative in both sub-samples, following the same path where for developed countries is about -1.03 and for developing countries is around -0.1.

>> INSERT Table 7 – EKC (1996-2002) and MEKC (1996-2004) <<

In order to compare results from standard EKC and MEKC, we have calculated the threshold values of GDP and HDIM where the EKC and the MEKC are maximised. Furthermore, in order to compare the two different measures, we have adopted a simple equation where HDIM is related to lnGDP, using a simplified formulation (eq. [7]) of the Human Development-Economic Growth causality nexus analysed by Ranis *et al*. (2000). The correlation used to transform the turning point for EKC from a GDP measure into a HDIM value is as follows:

$$HDIM = \beta_0 + \beta_1 \ln GDP + u_i \qquad [7]$$

where β_0 and β_1 are equal to (-0.48) and (+0.14) respectively. Therefore a maximum HDIM is available even for the standard EKC. The threshold HDIM for the MEKC is in the range 0.67-0.69, while the correspondent value for the EKC is in the range 0.81-0.84 (calculated for entire panel dataset in the period 1990-2004).

A full comparison of these two threshold levels is probably biased due to the fact that inside the AGS there is a component related to economic value of damage from CO_2 emissions. The EKC and the MEKC are partially correlated and results could be distorted. Therefore, we have performed a system of simultaneous equations, in order to eliminate this correlation.

Furthermore, considering that the ARCO index is statistically significant but in the MEKC it changes sign when an IV is performed, in the system of simultaneous equations we have tried to investigate this particular behaviour separating the ARCO index in its two components, the technological infrastructures (TECHINF) and the imported technology (TECHIMP).

>> INSERT Table 8 – EKC (1996-2002) and MEKC (1996-2004) simultaneous equations <<

Looking at the turning points, the gap between the turning points of the two alternative EKC formulations appears reduced in SURE model comparing to independent estimates. This is hardly surprising if we think about the model specification where the EKC and the MEKC have partially related dependent variables.

Furthermore, the investigation of separate components of technological progress allows better understanding the influence of technical progress on environmental degradation and sustainability. As we have expected, while the diffusion of basic technologies such as telephone and internet is related to the increase in the consumption patterns, with a consequent increase in the depletion and degradation of natural resources, at the same time the increase in imports of technologies induces the adoption of more environmental friendly production processes. An increase in FDI produces a shift of the industrial sector from the extraction of natural resources towards capital intensive production processes, implying a reduction of AGS.

6. Concluding remarks

The aim of this paper is to analyse the relationship between development and sustainability by using the empirical framework known as Environmental Kuznets Curve. In order to respond to criticisms moved to the EKC, we have introduced some modifications to the standard EKC. In particular, we have changed the dependent variable substituting a pure environmental stress as in the standard EKC with a wider assessment of sustainability defined by the Genuine Saving index provided by the World Bank. In order to reduce dissimilarities between a standard EKC and a modified EKC the GS was taken only in the components related to environmental degradation and depletion, hence accounting for a strong sustainability criterion. Furthermore, the income per capita as the driving factor of the *U*-shaped curve has been substituted with a broad definition of development based on the UNDP methodology of Human Development. Following recent EKC studies, the role of institutions has been analysed, but differently from other contributions it has been modelled as an endogenous variable. Finally, the role of technological progress has been introduced, modelled both as creation and diffusion of technology. Comparisons among alternative EKC formulations with different pollutants and the modified EKC have highlight the robustness of the latter, using a panel dataset with three temporal observations. A longer time series has been tested reinforcing results obtained for the MEKC with endogenous institutions. In the longer time series the role of technological progress has been strongly emerged, where diffusion of basic technologies are linked to increasing consumption and therefore reduced sustainability, while on the contrary imports of technologies help diffusing environmental friendly production processes, managing natural resources towards a sustainable path.

The formulation of the role of institutions as an endogenous covariate allows understanding which factors indirectly affect sustainable development. It is worth noting that initial conditions such as high levels of GDP per capita or health and education have positive effects in terms of institutional quality, and this result is useful to interpret the opposite effect of institutions for developed and developing countries. Within developing countries, especially those characterised by low development levels, the role of institutions is mainly directed towards the enhancement of basic needs and/or increasing economic performance, while environmental concerns are typically a luxury good. As well as income per capita and the development level raise, institutions are pressed by public opinion to include environmental protection in the policy agenda, therefore playing an active role to designate policy actions (and regulations) oriented towards sustainable development path.

Finally, we want to underline that the positive role of technological transfer through FDI reinforces the recent position of United Nations expressed by the Millennium Development Goals (UN, 2000) when claiming for an international cooperation for promoting human and sustainable development at a global level.

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Table 1 – EKC for CO_2 (years 1990-1995-2000)

Variables	CO_2 (1)		CO_2 (2)		CO_2 (3)	
Effects	Fixed Effects	Random Effects	Fixed Effects	Random Effects	Fixed Effects	Random Effects
GDP	2.741	2.735	11.407	11.406	8.660	8.651
	(10.28)*	(10.20)*	(6.15)*	(6.17)*	(6.06)*	(6.04)*
GDP^2	-0.125	-0.125	-1.135	-1.134	-0.766	-0.766
	(-7.34)*	(-7.27)*	(-4.79)*	(-4.80)*	(-4.14)*	(-4.13)*
GDP^3			0.039	0.039	0.023	0.023
			(3.94)*	(3.95)*	(2.92)*	(2.93)*
MAN	0.021	0.022	0.004	0.004	0.004	0.004
	(3.89)*	(3.96)*	(0.79)	(0.82)	(0.79)	(0.82)
IMP	-0.007	-0.006	-0.005	-0.005	-0.003	-0.002
	(-2.36)**	(-2.26)**	(-1.60)	(-1.56)	(-0.89)	(-0.68)
EXP	0.0102	0.011	0.007	0.007	0.005	0.005
	(3.36)*	(3.41)*	(2.31)**	(2.27)**	(1.99)**	(1.98)**
ENE			0.980	0.983	0.849	0.853
			(13.22)*	(13.32)*	(16.63)*	(16.76)*
DENS			0.001	0.001	0.0003	0.0003
			(2.35)**	(2.38)**	(1.76)***	(1.67)***
HDIM			0.471	0.480		
			(1.21)	(1.28)		
RL					0.146	0.126
					(2.19)**	(1.96)**
PAT					0.0002	0.0002
					(3.07)*	(3.12)*
CONST	-6.409	-6.416	-31.643	-31.665	-24.341	-24.351
	(-6.41)*	(-6.39)*	(-6.67)*	(-6.69)*	(-6.76)*	(-6.74)*
R-sq	0.749		0.881		0.885	
F test	240.39 (0.00)		207.37 (0.00)		270.37 (0.00)	
Wald test		1203.39 (0.00)		1896.55 (0.00)		2429.27 (0.00)
LM test for RE		1.02 (0.31)		0.90 (0.34)		0.00 (0.96)
F-test for EKC	378.02 (0.00)		114.95 (0.00)		243.90 (0.00)	
N. Obs.	408	408	267	267	324	324

Statistics for t-Student in parenthesis. * p-values < 0.01, ** p-values < 0.05, *** p-values < 0.1.
All estimates are modelled using robust standard errors in order to correct heteroskedasticity of the error term
F-test for EKC tests whether coefficients on GDP (HDIM) and GDP^2 ($HDIM^2$) are jointly zero, following Koop and Tole (1999).

Table 2 – EKC for SO_X (years 1990-1995-2000)

Variable	SO_X (1)		SO_X (2)		SO_X (3)	
Effect	Fixed Effects	Random Effects	Fixed Effects	Random Effects	Fixed Effects	Random Effects
GDP	1.758	1.751	14.020	14.117	9.046	9.059
	(4.15)*	(4.15)*	(2.18)**	(2.24)**	(1.79)***	(1.79)***
GDP^2	-0.081	-0.080	-1.479	-1.495	-0.835	-0.840
	(-3.11)*	(-3.11)*	(-1.84)***	(-1.90)***	(-1.32)	(-1.33)
GDP^3			0.054	0.054	0.025	0.025
			(1.62)	(1.68)***	(0.97)	(0.99)
MAN	0.003	0.002	-0.019	-0.020	-0.019	-0.020
	(0.36)	(0.30)	(-1.78)***	(-1.87)***	(-1.78)***	(-1.87)***
IMP	-0.014	-0.014	0.005	0.005	0.001	0.001
	(-3.88)*	(-3.89)*	(0.84)	(0.82)	(0.10)	(0.10)
EXP	0.010	0.011	0.001	0.001	0.002	0.002
	(2.71)*	(2.79)*	(0.08)	(0.14)	(0.26)	(0.36)
ENE			0.808	0.807	0.666	0.655
			(5.73)*	(5.73)*	(4.55)*	(4.51)*
DENS			-0.0002	-0.0002	0.000	-0.00001
			(-0.80)	(-0.82)	(0.00)	(-0.05)
HDIM			-1.308	-1.157		
			(-1.48)	(-1.33)		
RL					0.267	0.229
					(1.42)	(1.32)
PAT					-0.0003	-0.0003
					(-4.95)*	(-4.80)*
CONST	1.130	1.150	-34.127	-34.381	-21.866	-21.890
	(0.68)	(0.70)	(-2.04)**	(-2.09)**	(-1.66)	(-1.66)***
R-sq	0.37		0.528		0.552	
F test			51.39 (0.00)		56.08 (0.00)	
Wald test		380.96 (0.00)		474.21 (0.00)		493.64 (0.00)
LM test for RE		0.70 (0.40)		0.99 (0.32)		0.37 (0.54)
F-test for EKC			29.44 (0.00)		36.00 (0.00)	
N. Obs.	420	420	268	268	327	327

Statistics for t-Student in parenthesis. * p-values < 0.01, ** p-values < 0.05, *** p-values < 0.1.
All estimates are modelled using robust standard errors in order to correct heteroskedasticity of the error term
F-test for EKC tests whether coefficients on GDP (HDIM) and GDP^2 ($HDIM^2$) are jointly zero, following Koop and Tole (1999).

Table 3 – EKC for NO_X (years 1990-1995-2000)

Variable	NO_X (1)		NO_X (2)		NO_X (3)	
Effects	Fixed Effects	Random Effects	Fixed Effects	Random Effects	Fixed Effects	Random Effects
GDP	0.286	0.295	0.165	0.172	0.073	0.077
	(0.84)	(0.98)	(0.05)	(0.06)	(0.03)	(0.04)
GDP^2	-0.003	-0.004	-0.027	-0.028	0.008	0.007
	(-0.15)	(-0.21)	(-0.07)	(-0.08)	(0.03)	(0.03)
GDP^3			0.003	0.003	0.000	0.000
			(0.17)	(0.18)	(-0.04)	(-0.04)
MAN	-0.015	-0.015	-0.008	-0.008	-0.008	-0.008
	(-2.26)**	(-1.61)	(-0.59)	(-0.61)	(-0.59)	(-0.61)
IMP	-0.007	-0.007	-0.003	-0.003	-0.007	-0.008
	(-1.91)**	(-2.01)**	(-0.49)	(-0.49)	(-1.48)	(-1.57)
EXP	0.003	0.003	-0.002	-0.002	-0.001	0.000
	(0.90)	(0.81)	(-0.30)	(-0.31)	(-0.12)	(-0.09)
ENE			-0.060	-0.058	-0.097	-0.102
			(-0.66)	(-0.65)	(-1.42)	(-1.51)
DENS			-0.001	-0.001	-0.001	-0.001
			(-4.75)*	(-4.75)*	(-4.23)*	(-4.26)*
HDIM			-0.531	-0.518		
			(-0.94)	(-0.92)		
RL					0.157	0.164
					(1.42)	(1.52)
PAT					0.000	0.000
					(0.09)	(0.06)
CONST	4.613	4.590	6.124	6.097	5.819	5.837
	(3.66)*	(4.13)*	(0.79)	(0.79)	(1.06)	(1.06)
R-sq	0.113		0.230		0.210	
F test	10.48 (0.00)		10.53 (0.00)		13.09 (0.00)	
Wald test		49.95 (0.00)		93.43 (0.00)		120.81 (0.00)
LM test for RE		0.87 (0.35)		1.26 (0.23)		1.03 (0.31)
F-test for EKC	18.74 (0.00)		0.02 (0.98)		0.22 (0.80)	
N. Obs.	414	414	268	268	327	327

Statistics for t-Student in parenthesis. * p-values < 0.01, ** p-values < 0.05, *** p-values < 0.1.
All estimates are modelled using robust standard errors in order to correct heteroskedasticity of the error term
F-test for EKC tests whether coefficients on GDP (HDIM) and GDP^2 ($HDIM^2$) are jointly zero, following Koop and Tole (1999).

Table 4 – EKC for AGS (years 1990-1995-2000)

Variable	AGS (1)		AGS (2)		AGS (3)	
Effects	Fixed Effects	Random Effects	Fixed Effects	Random Effects	Fixed Effects	Random Effects
HDIM	13.929 (6.46)*	13.921 (6.33)*	8.631 (2.83)*	8.793 (2.86)*	16.946 (5.00)*	16.700 (4.97)*
$HDIM^2$	-7.311 (-4.20)*	-7.447 (-4.18)*	-4.462 (-1.68)***	-4.722 (-1.78)***	-10.865 (-3.78)*	-10.759 (-3.82)*
$HDIM^3$			1.812 (1.58)	1.747 (1.56)	0.483 (0.46)	0.523 (0.51)
MAN	-0.012 (-1.08)	-0.010 (-0.96)	-0.013 (-0.84)	-0.011 (-0.73)	-0.013 (-0.84)	-0.011 (-0.73)
IMP	-0.068 (-7.30)*	-0.069 (-7.25)*	-0.042 (-3.18)*	-0.043 (-3.06)*	-0.035 (-3.01)*	-0.036 (-2.98)*
EXP	0.070 (7.68)*	0.071 (7.52)*	0.050 (3.82)*	0.051 (3.61)*	0.043 (3.84)*	0.044 (3.78)*
ENE			-0.089 (-0.80)	-0.120 (-1.06)	0.058 (0.46)	0.039 (0.31)
DENS			-0.001 (-1.95)***	-0.001 (-1.98)**	-0.001 (-2.26)**	-0.001 (-2.23)**
OIL			1.594 (5.90)*	1.603 (5.81)*	1.910 (8.03)*	1.904 (7.95)*
RL					0.522 (4.06)*	0.516 (4.13)*
PAT					0.0003 (1.54)	0.0003 (1.58)
CONST	-1.898 (-3.07)*	-1.822 (-2.91)*	-0.863 (-0.95)	(-0.78)	-3.231 (-3.20)*	-3.110 (-3.09)*
R-sq	0.533		0.584		0.653	
F test	92.14 (0.00)		52.78 (0.00)		63.87 (0.00)	
Wald test		449.86 (0.00)		461.11 (0.00)		621.74 (0.00)
LM test for RE		0.69 (0.41)		0.65 (0.42)		0.51 (0.47)
F-test for EKC	70.01 (0.00)		5.43 (0.00)		15.41 (0.00)	
N. Obs.	367	367	246	246	284	284

Statistics for t-Student in parenthesis. * p-values < 0.01, ** p-values < 0.05, *** p-values < 0.1.
All estimates are modelled using robust standard errors in order to correct heteroskedasticity of the error term
F-test for EKC tests whether coefficients on GDP (HDIM) and GDP^2 ($HDIM^2$) are jointly zero, following Koop and Tole (1999).

Table 5 – EKC for CO_2 and AGS, IV (years 1990-1995-2000)

Variable	AGS (1)	AGS (2)	CO2 (1)	CO2 (2)
HDIM / GDP	12.488	12.586	4.781	11.674
	(4.37)*	(3.73)*	(16.91)*	(6.32)*
$HDIM^2$ / GDP^2	-7.765	-6.504	-0.242	-1.112
	(-3.18)*	(-1.63)**	(-13.90)*	(-4.81)*
HDM^3 / GDP^3		-1.339		0.036
		(-0.67)		(3.77)*
IMP	-0.057	-0.055	-0.013	-0.012
	(-6.40)*	(-5.37)*	(-2.99)*	(-2.97)*
EXP	0.062	0.061	0.010	0.009
	(7.23)*	(6.13)*	(2.42)**	(2.34)**
ENE			1.081	1.240
			(10.85)*	(11.75)*
DENS	-0.001	-0.001	0.001	0.001
	(-3.60)*	(-3.21)*	(2.83)*	(3.31)*
OIL	1.463	1.406		
	(7.04)*	(6.23)*		
RL	0.532	0.579	0.232	0.228
	(4.32)*	(4.13)*	(3.27)*	(3.30)*
CONST	-1.169	-1.347	-15.117	-33.066
	(-1.53)	(-1.52)	(-12.82)*	(-6.75)*
R-sq	0.662	0.657	0.897	0.904
Wald test	2944.94 (0.00)	2465.93 (0.00)	65966.31 (0.00)	69874.17 (0.00)
Hausman endogeneity	30.56 (0.00)	21.76 (0.00)	18.82 (0.01)	51.00 (0.00)
Overid test (Sargan)	45.09 (0.00)	44.84 (0.00)	22.52 (0.00)	15.03 (0.01)
F-test for EKC	54.97 (0.00)	26.86 (0.00)	482.84 (0.00)	399.27 (0.00)
Wald omitted Cubic Term		0.07 (0.79)		14.22 (0.00)
N. Obs.	288	288	234	234

Statistics for t-Student in parenthesis. * p-values < 0.01, ** p-values < 0.05, *** p-values < 0.1.
Instruments for RL: HDIM70, GDP70, HDIMCH, INV, INFLA.

Table 6 – Unit root tests for EKC and MEKC (1990-2004)

	LL	IPS	MW(ADF)	MW(PP)
		Fixed Effects		
AGS	-6.561*	-4.386*	499.15*	668.43*
HDIM	-0.948	4.992	257.62	246.57
CO_2	-11.183*	-1.164	501.81*	465.86*
GDP	-15.748*	-5.177*	444.46*	332.83**
		Fixed Effects with Trend		
AGS	-16.584*	-6.064*	663.06*	627.96*
HDIM	-13.322*	-0.906	556.27*	1277.02*
CO_2	-15.880*	-1.940*	540.95*	541.51*
GDP	-29.823*	-7.538*	655.62*	576.83*

Notes:
For AGS and HDIM time series is 1990-2004, while for CO_2 and GDP time series is 1990-2002.
In the LL test (Levin-Lin-Chu) for unit root the t-statistic has a standard normal distribution under the null hypothesis of non-stationarity.
In the IPS test (Im-Pesaran-Shin) for unit root the W[t-bar] statistic is distributed standard normal under the null hypothesis of non-stationarity.
Fisher type statistic, developed among the others by developed by Maddala and Wu (MW test), combines the p-values from N independent unit root tests. Based on the p-values of individual unit root tests, the test assumes that all series are non-stationary under the null hypothesis against the alternative that at least one series in the panel is stationary. It is modelled both as an Augmented Dickey-Fuller test (ADF) and as a Phillips-Perron test (PP).
All the tests have been performed with STATA 9.2.

Table 7 – EKC (1996-2002) and MEKC (1996-2004), independent estimates

Variable	AGS	AGS-IV	CO_2	CO_2-IV
HDIM / GDP	5.774	14.951	5.831	5.462
	(2.63)*	(8.42)*	(18.98)*	(10.05)*
$HDIM^2$ / GDP^2	-4.156	-11.097	-0.314	-0.288
	(-3.84)*	(-7.14)*	-(-15.08)*	(-7.74)*
IMP	-0.051	-0.044	-0.010	-0.009
	(-13.83)*	(-12.02)*	(-3.19)*	(-3.52)*
EXP	0.058	0.050	0.012	0.011
	(14.95)*	(13.88)*	(3.72)*	(4.95)*
MAN	0.005	0.019	0.006	0.006
	(0.78)	(3.21)*	(2.33)**	(1.92)**
INV	0.000		-0.001	
	(-0.17)		(-1.32)	
ENE			0.760	0.755
			(8.25)*	(20.35)*
DENS	-0.001	-0.002	0.0004	0.0004
	(-4.40)*	(-6.26)*	(5.29)*	(2.84)*
OIL	1.989	2.286		
	(15.71)*	(19.09)*		
RL	0.376	1.345	0.058	-0.051
	(6.52)*	(10.01)*	(1.27)	(-0.41)
ARCO	1.187	-1.654	0.913	0.895
	(1.75)**	(-2.44)*	(2.82)*	(2.83)*
HDIM (1 lag)	2.586	1.106		
	(1.41)	(0.58)		
CONST	-0.739	-1.357	-24.751	-23.542
	(-2.14)**	(-2.99)*	(-18.46)*	(-12.00)*
R-sq	0.71	0.64	0.90	0.90
F-test	251.33 (0.00)		827.9 (0.00)	
Wald test		12280 (0.00)		179008 (0.00)
Hausman endogeneity		60.71 (0.00)		5.22 (0.81)
Overid test (Sargan)		48.55 (0.00)		54.88 (0.00)
F-test for EKC	7.59 (0.00)	98.14 (0.00)	649.24 (0.00)	
N. Obs.	1072	1072	728	728
Turning Point (HDIM)	0.69	0.67	0.81	0.84

Table 8 – EKC (1996-2002) and MEKC (1996-2004), simultaneous equations

	SURE		3SLS	
Variable	AGS	CO_2	AGS	CO_2
HDIM / GDP	10.745	5.629	10.635	3.473
	(4.26)*	(15.22)*	(4.02)*	(6.19)*
$HDIM^2$ / GDP^2	-6.824	-0.300	-6.785	-0.134
	(-3.46)*	(-12.82)*	(-3.28)*	(-3.63)*
IMP	-0.071	-0.014	-0.067	-0.007
	(-13.35)*	(-5.21)*	(-12.26)*	(-2.26)**
EXP	0.074	0.018	0.070	0.013
	(15.29)*	(7.31)*	(14.12)*	(4.50)*
MAN	-0.028	0.007	-0.022	0.006
	(-3.64)*	(1.77)**	(-2.76)*	(1.38)
INV	-0.0002	-0.0004	-0.001	0.0002
	(-0.26)	(-0.83)	(-0.74)	(0.34)
ENE		0.0002		0.0001
		(11.26)*		(0.77)
DENS	-0.001	0.0001	-0.001	0.0002
	(-1.99)**	(0.50)	(-1.95)**	(10.15)*
OIL	1.373		1.560	
	(11.74)*		(12.60)*	
RL	0.149	0.023	0.346	-1.043
	(1.75)**	(0.44)	(2.62)*	(-8.55)*
TECHINF	3.889	2.651	3.079	3.681
	(5.96)*	(6.87)*	(3.80)*	(8.05)*
TECHIMP	-0.733	-0.027	-0.648	-0.248
	(-1.82)**	(-0.12)	(-1.80)**	(-1.05)
CONST	-1.311	-19.849	-1.143	-14.056
	(-1.71)**	(-13.62)*	(-1.46)	(-6.84)*
R-sq	0.71	0.88	0.71	0.81
F-test	1522	4480.24	1551.92	3951.7
F-test for EKC	32.70 (0.00)	472.06 (0.00)	29.31 (0.00)	535.01 (0.00)
N. Obs.	624	624	624	624
Turning Point (HDIM)	0.79	0.82	0.78	1.32

Appendix A: Tab A1 - Main Statistics

Variable	Mean	Std. Dev.	Min	Max
CO_2	7.67	1.47	3.04	10.33
GDP	8.72	1.09	6.58	10.94
GDP^2	77.30	18.98	43.50	119.85
AGS	3.52	2.04	0.07	9.00
HDIM	0.69	0.19	0.24	0.96
$HDIM^2$	0.52	0.25	0.06	0.93
IMP	42.35	21.98	7.59	183.68
EXP	37.96	23.12	5.21	192.54
MAN	15.17	7.40	0.52	42.51
INV	21.24	43.39	0.20	848.85
ENE	2243.64	2346.53	75.23	11722.36
RL	0.07	0.98	-1.97	2.36
HDIM70	0.60	0.21	0.17	0.90
HDIMCH	0.20	0.18	-0.34	1.10
GDP70	8.32	1.10	6.17	10.67
INFLA	13.90	51.74	-23.48	879.86
PAT	49.31	301.97	0	4892.61
ARCO	0.22	0.12	0	0.74

Appendix A: Tab A2 - Correlation matrix

	AGS	HDIM	$HDIM^2$	DENS	IMP	EXP	MAN	INV	OIL	RL	HDIM70	HDIMCH	GDP70	INFLA
HDIM	0.597													
$HDIM^2$	0.581	0.991												
DENS	-0.020	0.138	0.136											
IMP	0.047	0.145	0.126	0.053										
EXP	0.385	0.301	0.283	0.061	0.851									
MAN	0.208	0.497	0.491	0.176	0.128	0.179								
INV	0.221	0.219	0.231	0.276	0.252	0.351	0.091							
OIL	0.487	0.039	0.005	-0.059	-0.174	0.038	-0.177	0.062						
RL	0.464	0.701	0.738	0.134	0.152	0.297	0.295	0.285	-0.132					
HDIM70	0.552	0.947	0.949	0.102	0.191	0.337	0.515	0.225	-0.040	0.675				
HDIMCH	-0.282	-0.469	-0.480	0.011	-0.185	-0.266	-0.341	-0.140	0.122	-0.311	-0.702			
GDP70	0.682	0.844	0.861	0.094	0.110	0.328	0.372	0.265	0.090	0.778	0.849	-0.486		
INFLA	-0.024	-0.131	-0.132	-0.084	0.008	0.041	-0.065	-0.035	0.069	-0.229	-0.086	-0.064	-0.104	
ARCO	0.411	0.704	0.730	-0.003	0.353	0.427	0.312	0.346	-0.147	0.694	0.735	-0.502	0.694	-0.152

	CO_2	GDP	GDP^2	IMP	EXP	DENS	ENE	MAN	INV	RL	HDIM70	GDP70	HDIMCH	INFLA
GDP	0.900													
GDP^2	0.890	0.998												
IMP	0.091	0.043	0.038											
EXP	0.317	0.243	0.242	0.868										
DENS	-0.088	-0.041	-0.035	-0.029	-0.066									
ENE	0.742	0.753	0.770	0.013	0.213	-0.045								
MAN	0.328	0.393	0.381	0.155	0.189	0.105	0.056							
INV	0.150	0.198	0.211	0.289	0.329	-0.016	0.190	0.059						
RL	0.763	0.884	0.898	0.087	0.252	0.008	0.753	0.347	0.194					
HDIM70	0.774	0.842	0.837	0.107	0.211	-0.048	0.605	0.467	0.141	0.714				
GDP70	0.887	0.966	0.963	0.032	0.205	-0.088	0.737	0.327	0.163	0.824	0.848			
HDIMCH	-0.429	-0.471	-0.473	-0.154	-0.173	0.132	-0.375	-0.335	-0.105	-0.382	-0.769	-0.525		
INFLA	-0.078	-0.123	-0.127	0.055	0.089	-0.069	-0.093	-0.080	-0.017	-0.180	-0.068	-0.111	-0.050	
ARCO	0.660	0.741	0.749	0.353	0.427	-0.003	0.543	0.312	0.346	0.694	0.735	0.694	-0.502	-0.152

Appendix A: Table A3 - Data definitions

Code	Definition
AGS	Natural logarithm of Genuine Saving per capita (constant PPP2000$)
CO_2	Natural logarithm of CO_2 emissions (ton. per capita)
NO_X	Natural logarithm of NO_X emissions (ton. per capita)
SO_X	Natural logarithm of SO_X emissions (ton. per capita)
GDP	Natural Logarithm GDP per capita (constant PPP2000$)
HDIM	Human Development Index, standard UNDP methodology without GDP Index
IMP	Total Imports of merchandise goods as % of GDP
EXP	Total Exports of merchandise goods as % of GDP
MAN	Industry, value added (% of GDP)
INV	Gross private capital flows (% of GDP)
DENS	Population density (people per sq. km)
ENE	Energy use (kg of oil equivalent per capita)
OIL	Dummy for main oil exporting countries
PAT	Patent applications, residents (% of GDP)
ARCO	Technological Capabilities Index (Archibugi and Coco, 2004)
TECHINF	Technological Infrastructures (based on telephone and internet penetration)
TECHIMP	Import of technology (based on FDI inflows)
RL	Rule of Law (Kauffman et al., 2003)
HDIM70	Initial level of HDIM
HDIMCH	Change in HDIM level from initial time period until present observation
GDP70	Initial level of GDP per capita (constant PPP2000$)
INFLA	Natural logarithm of Inflation rate (GDP deflator)