Quaderni di Dipartimento

Innovation and the environmental Kuznets curve: the case of CO, NMVOCs and SOx in the Italian regions

Donatella Baiardi
(Università di Pavia)

156 (01-12)

Dipartimento di economia politica
e metodi quantitativi
Università degli studi di Pavia
Via San Felice, 5
I-27100 Pavia

Gennaio 2012

Innovation and the environmental Kuznets curve: the case of CO, NMVOCs and SO_x in the Italian regions

Donatella Baiardi*

January 16, 2012

Abstract

The paper explores the relationship between per capita income and three air pollutants, CO, NMVOCs and SO_x, using a novel dataset based on the Italian regions. Given the central role of technological progress in long-term environmental problems, we empirically investigate the influence of innovation on the environmental Kuznets curve (EKC). The estimation results validate the EKC hypothesis for the three air pollutants considered. Furthermore, the influence of innovation on the inverted-U-shaped curve identified by the theoretical literature is empirically confirmed too.

Key words and phrases: Air pollutants, Environmental Kuznets Curve, Italian regions, Technological Progress.

*Dipartimento di Economia, Statistica e Diritto, Via Strada Nuova 65, Università degli Studi di Pavia, Pavia, IT-27100, Italy. Tel.: +39 0382 986227; fax: +39 0382 304226. Email address: dbaiardi@eco.unipv.it

1 Introduction

The environmental Kuznets curve (hereafter EKC) describes the relationship between environmental quality and per capita income. During the early stage of development, when the level of per capita income is low and the economy is being revolutionized by the industrialization process, pollution tends to increase rapidly. Afterwards, when high income levels are reached (post-industrial economy or service economy), the trend reverses because of the higher levels of environmental protection, an increase in environmental awareness and technological improvements in abatement. This inverse empirical relationship, represented as an inverted-U-shaped line,[1] was discovered by Grossman & Krueger (1991), when they were testing the impact of Mexico's inclusion in NAFTA on pollution. The result was surprising and has been widely investigated in the last twenty years, mainly through pooled panel data of different sets of countries. There are many surveys summing up the empirical evidence, for example see Stern (1998, 2004) and Dinda (2004). Findings are mixed and the debate on the validity of the EKC and its main determinants is still open.

Andreoni & Levinson (2001) provide a microfoundation of the EKC by means of a straight-forward static model. They find that it depends directly on the technological link between consumption of a desired good and abatement of its undesiderable byproduct. Chimeli & Braden (2005) present a theoretical model where differences across units in total factor productivity produce a cross-sectional EKC. Their simulations also indicate the existence of a critical value of Total Factor Productivity (TFPs) such that higher TFPs are associated with better environmental quality. Furthermore, Smulders et al. (2011) identify endogenous innovations, policy-induced technology shifts and intrasectoral changes as the theoretical foundation of the EKC.[2] As far as we know, in spite of the central role of technological progress in the theoretical studies of the EKC, in the empirical single country literature technology is only occasionally explicitly introduced as a control variable, generally represented by proxies like energy consumption, which proves to be the main cause of CO_2 emissions in Ang (2007), Iwata et al. (2010) and Nasir & Rehman (2011). It is important to note that in the case of panel data,[3] ignoring country-specific characteristics highly correlated with income, such as technological progress, may imply bias and inconsistent estimations.

For these reasons this paper explicitly investigates the role of innovation in the inverse-U-shaped relationship between per capita income and pollution. In particular, we follow

[1] Panayotou (1993) is the first author that named this evidence environmental Kuznets curve, because of the similarity with the inverted-U-shaped relationship between per capita income and inequality studied by Kuznets (1955). Selden & Song (1994) used this denomination for the first time in an academic journal.

[2] On the role of innovation in the EKC, see also Johansson & Kriström (2007) and Brock & Taylor (2010).

[3] Ang (2007), Iwata et al. (2010) and Nasir & Rehman (2011) use a time series approach.

the methodology proposed by Leitão (2010), who studies the role of corruption in the EKC using a wide cross-national panel of countries. We first estimate the effects of innovation on per capita income, which may indirectly influence the EKC. Secondly, we check the validity of the EKC and the role of innovation on its turning point, the maximum level of the EKC in correspondence to which environmental quality begins to improve as per capita income further increases. We use for the first time a new panel data based on the twenty regions of Italy. In fact, if the EKC holds, when a country (or, as in our case, a region) becomes rich, people give much more attention to the preservation of the environment; governments implement policies for environmental protection and technological progress encourages the use of many more renewable resources and the introduction of more advanced machinery in the manufacturing process. Abatement processes become less expensive. For these reason, in line with the positive relationship between a certain critical value of TFPs and environmental quality theoretically identified by Chimeli & Braden (2005), innovation activities may influence the turning point of the EKC; the more innovative a country (region), the lower is the level of the turning point of the EKC where pollution begins to decrease.

In this paper, we focus on three local pollutants, CO (carbon monoxide), NMVOCs (non-methane volatile organic compounds) and SO_x (sulphur oxides).[4] Few papers in the single country literature investigate the EKC hypothesis for CO and NMVOCs, since time series data on the two pollutants are generally short. Differing results are found for CO by Carson et al. (1997) and Khanna (2002), while Roca et al. (2001) uncover mis-specifications in the estimation of the EKC for NMVOCs. The EKC is identified for SO_x in the 50 US States by List & Gallet (1999) and by Millimet et al. (2003), in Spain by Roca et al. (2001) and in Tunisia by Fodha & Zaghdoud (2010).[5] CO and NMVOCs are ozone precursors, because they contribute to the formation of tropospheric ozone, which indirectly affects human and animal health and vegetation (European Commission, 1999). CO is also present in volcano eruptions, forest fires, and other forms of combustion. NMVOCs are directly related to the use of organic solvents and contribute to the formation of photo-oxidants and photochemical smog. Finally, SO_x emissions produce sulphate aerosols in the troposphere and they are responsible for the acidification process with dangerous effects on human health.

The paper proceeds as follows. Section 2 reviews the EKC literature, with a special focus on single country studies. Section 3 presents the model and Section 4 describes

[4] We indicate as SO_x the sum of SO_2 (sulphur dioxide) and SO_3 (sulphur trioxide).

[5] The case of CO_2 is often studied in the single country literature. It is classified as a 'global pollutant' because it causes problems on global scale with consequences in terms of global warming across time and nations. Given data availability (time series of CO_2 are available at country level for many years, generally from the 1960s onwards) and the nature of this pollutant, Friedl & Gezner (2003) state that a time series analysis is more appropriate than a panel data approach (See also Aldy 2004, Ang 2007, Cialani 2007, Akbostanci et al. 2009, Jalil & Mahmud 2009, Iwata et al. 2010 and Nasir & Rehman 2011.)

the data used in the estimations. Section 5 shows and discusses the estimation results. Section 6 concludes the paper.

2 A literature review

Grossman & Krueger (1991) proved for the first time the existence of the EKC for sulphur dioxide (SO_2) and dark matter (smoke). They found that three phenomena determine the nature of the relationship between income and environmental degradation: scale effects, composition effects and technology sophistication. Scale effects are related to the increasing volume of production over time. Higher output requires more inputs (such as natural resources) and therefore a deterioration of the environment. Composition and technological effects concern the positive influence of development on environmental quality. Economic growth allows a transformation from agriculture to industry and finally to services (composition effects). During the first phase, from agriculture to industry, there is a deterioration of environmental conditions due to the increase in polluting industrial production, but in the next phase, the evolution toward services reduces pollution. Finally, technological effects make production technique more advanced and there is more focus on abatement, with the adoption of newer and cleaner technologies. For example, a large number of studies widen and investigate these findings: Shafik & Bandyopadhyay (1992), Panayotou (1993), Selden & Song (1994) and then again Grossman & Krueger (1995) confirm the EKC hypothesis for many different pollutants.

The traditional empirical specification of the EKC uses a pollutant as the dependent variable. The main independent variable is wealth, traditionally per capita income, expressed either in level, in square or eventually in cubic form, in order to identify any possible functional form which differs from the canonical EKC. Recently, Bradford et al. (2005) propose a new and more robust specification of the EKC, in order to overcome the use of nonlinear transformations of potentially nonstationary regressors in panel estimation (generally, per capita income has a unit-root behaviour). These new specifications also avoid the cross-sectional dependence caused by the presence of unit-roots nonstationary variables.[6] Other control variables, which can explain the dynamics of environmental degradation and wealth, can be introduced.[7]

Table 1 near here

[6] Bradford et al. (2005) note that this alternative specification is also valid if per capita income is a stationary variable.

[7] The reduced form specification is only based on income. Panayotou (1997) underlines that '*the EKC, in its reduced form, is a 'black box' that hides more than it reveals. We are left without any clue as to why the observed relationship exists and how to influence it. Without an explicit consideration of the underlying determinants of environmental quality, the scope for policy intervention is unduly circumscribed. Therefore, estimation of a reduced-form EKC should only be a first step in our effort to understand the environment-development relationship, not the endpoint*'.

Nowadays an increasing body of papers analyzes the validity of the EKC hypothesis for a single nation. Table 1 provides a chronological list of the single country EKC studies. The columns report the name(s) of the author(s), the country and the estimated functional forms. The EKC hypothesis is verified for NO_x and SO_2 in the 50 US States according to List & Gallet (1999), Millimet et al. (2003) and only for SO_2 in Spain (Roca et al., 2001). The inverse-U-shaped relationship between environmental degradation and per capita income is also proved for CO_2 in the United States (Aldy, 2005) and in France (Ang, 2007 and Iwata et al., 2010). Using micro data Kahn (1998) tests successfully the EKC for vehicle hydrocarbon emissions and median household income in California. To our knowledge, there are few papers which study the EKC hypothesis in developing countries: it is verified only for SO_2 in Tunisia (Fodha & Zaghdoud, 2010), for CO_2 in China (Jalil & Mahmud, 2009), in Tunisia (Fodha & Zaghdoud, 2010) and in Pakistan (Nasir & Rehman 2011), but not for air and different water pollutants in Malaysia (Vincent, 1997).

In fact, although the literature generally finds that the relationship between economic growth and environmental degradation is described by an inverse-U-shaped figure, this is not always confirmed by empirical evidence, which calls into question the real existence of the EKC.[8] Khanna (2002) extends Kahn's analysis, but the result is a U-shaped relationship instead of the inverted-U-shaped EKC.[9] Many other papers do not find the EKC hypothesis to hold: for example a linear trend is found for seven air pollutants in the 50 US States in the period between 1988 and 1994 (Carson et al., 1997) and for CO_2 in Italy (Cialani, 2007), in Turkey (Akbostancı et al., 2009) and in Canada (He & Richard, 2010), while an N-shaped curve holds for this last pollutant in Austria (Friedl & Getzner, 2003) and for PM_{10} and SO_2 in Turkey (Akbostancı et al., 2009). No relationship is identified in Greece (Lekakis, 2000).

3 The Model

The relationship between measures of pollution, per capita income and other possible control variables is traditionally estimated in the literature by means of the following equation (see, for example Khanna 2004, Stern 2004, Ang 2007 and Orubu & Omotor 2011):

$$X_{it} = \beta_0 + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 Z_{it} + \epsilon_{it} \tag{1}$$

where i and t refer to the i-th region and the year respectively. X_{it} is the environmental stress and Y_{it} is the wealth indicator, generally represented by per capita GDP. Z_{it}

[8] The debate about the robustness of the EKC hypothesis is formally analyzed by Stern (2004) and Galeotti et al. (2009).

[9] All the various possible relationships between environmental stress and economic development, which differ to the inverse-U-shaped figure, are for example summarized by Dinda (2004), pp. 440.

indicates other variables with potentially explanatory power. We introduce the control variables used in our analysis at the end of this section.

Bradford et al. (2005) propose a new specification of Equation (1) in order to best describe the long-term interaction between pollution and wealth. For simplicity, we omit the subscript i and the other possible explanatory variables. The schematic relationship between the rate of change of environmental degradation and income and its growth rate at a given point of time is as follows:

$$\frac{\partial P_t}{\partial t} = \alpha(y - y^\star)g, \tag{2}$$

where the instantaneous change of pollution depends on the income growth rate g and on the distance of income y to its turning point $y^\star$. When $g > 0$, the EKC is verified if $\alpha < 0$, so pollution increases when $y < y^\star$ while the trend reverses when $y > y^\star$.

In the theoretical literature, Chimeli & Braden (2005) indicate that a cross-sectional EKC is obtained when technology shows decreasing returns to scale.[10] Following Leitão (2010), we extend Bradford et al. (2005) model in order to capture the role of innovation on the EKC and on its turning point as follows:

$$y^\star = \lambda_1 + \lambda_2 T, \tag{3}$$

where λ_1 is a generic constant and T is the average innovation level over the sample period in each region. Equation (3) directly formalizes the negative linkage between higher level of technological progress (and income) and pollution. In addition, it allows computation of the EKC considering explicitly those region-specific characteristics generally neglected in the empirical literature, since fixed or random effects cannot entirely capture them (See also Chimeli & Braden, 2005). In Equation (3), the turning point $y^\star$ is an inverse function of the region's level of technological progress. This implies that $\lambda_2 < 0$, i.e. the turning point of the EKC is reached at a lower income level than the level of a less innovative region, in a sort of 'environmental catching up'.[11] This is in line with the technological sophistication that relies under the hypothesis of the existence of an inverse-U-shaped relationship between economic growth and pollution. When per capita income reaches high levels, people develop more awareness toward the environment, policy makers give much more attention to environmental protection and newer and cleaner production methods are introduced.

[10]This is in contrast with Andreoni & Levinson (2001), whose model requires increasing returns to pollution abatement to obtain the EKC.

[11]Brock & Taylor (2010) find that the EKC is the result of the convergence to a sustainable growth path when technological progress in abatement is introduced in the Solow model (they recall the Solow model as the 'Green Solow Model'). The EKC turning point does not coincide with the steady state of the 'Green Solow Model'. In fact, if growth is sustainable, the EKC turning point is reached at a lower level of capital per effective worker than the level for the steady state.

We substitute Equation (3) into Equation (2), in order to get:

$$\frac{\partial P_t}{\partial t} = \alpha[y - (\lambda_1 + \lambda_2 T)]g. \tag{4}$$

We then integrate Equation (4) with respect to time, considering y and g as the average income level and growth rate as constant in the sample period. We obtain that:

$$P_t = \mu + \alpha[y - (\lambda_1 + \lambda_2 T)]gt, \tag{5}$$

where μ is a constant of integration. The equation to be estimated is obtained (including again the subscript i to indicate each region) by adding to Equation (5) the individual-specific effects μ_i, the control variables Z_{it} and the error term ϵ_{it}. So we get

$$P_{it} = \mu_i + \beta_0(y_i g_i t) + \beta_1(g_i t) + \beta_2(T_i g_i t) + \beta_3 Z_{it} + \epsilon_{it}. \tag{6}$$

In this paper we estimate the new specification of the EKC according to Equation (6) for three different pollutants (P_{it}): per capita carbon monoxide emissions (CO_{it}), per capita non-methane volatile organic compounds ($NMVOCs_{it}$) and per capita sulphur oxides (SOX_{it}). Variable y_i is the region-specific measure of average per capita GDP, variable g_i is the region-specific growth rate of per capita income, and variable T_i is the region-specific average degree of technology in the sample period. Z_{it} is a set of control variables widely used in the literature, such as the literacy rate (see, for example GANGADHARAN & VALENZUELA, 2001 and ORUBU & OMOTOR, 2011) and some measures of trade and structural change introduced for the first time by SURI & CHAPMAN (1998). See the following section for a more detail description of the variables introduced in Equation (6).

According to BRADFORD ET AL. (2005), the EKC is verified if $\alpha < 0$, so if $\beta_0 < 0$, given that $\alpha = \beta_0$. Furthermore, given the inverse relationship between the turning point $y^\star$ and the technological progress indicated by the condition $\lambda_2 < 0$ explained in Equation (3), we have that $\beta_2 = -\alpha\lambda_2 < 0$. The sign of the coefficient β_1 depends on the generic constant λ_1. In fact, in our model $\beta_1 = -\alpha\lambda_1 > 0$ if $\lambda_1 > 0$ and vice versa.[12] Contrary to BRADFORD ET AL. (2005) and analogously to LEITÃO (2010), this new specification of the EKC does not allow estimation of the turning point $y^\star$. However, it is possible to test the parameter condition on $\lambda_2 = -\frac{\beta_2}{\alpha} < 0$ and the sign of $\lambda_1 = -\frac{\beta_1}{\alpha}$, which determines the sign of β_1, in order to verify the hypothesis introduced by the theory and to check formally the signs of the coefficients β_1 and β_2.

As in LEITÃO (2010) we proceed in two phases. In the growth literature authors such as ISLAM (1995), CASELLI ET AL. (1998), DOWRICK & ROGERS (2002) and BIANCHI ET AL. (2009) claim that neglecting the close linkage between per capita income level and country-specific effects typically related to technological differences may produce misleading results. For this reason, we first estimate per capita income in order to consider

[12] Note that LEITÃO (2010) does not give any specific indication about the sign of the coefficient β_1, which is negative in her estimations.

technological differences across regions, according to Equation (7). Secondly we estimate Equation (6) using fitted values of per capita income previously obtained from Equation (7):

$$Y_{it} = \omega_i + \delta_1 RD_{it} + \delta_2 S_{it} + \delta_3 X_{it} + \xi_{it}. \tag{7}$$

Per capita income Y_{it} is expressed as a function of technological progress, proxied by regional expenditure on RD_{it}, and of per capita gross investment S_{it}, as a proxy of capital accumulation. As in LEITÃO (2010) a set of control variables (X_{it}) widely used in the growth literature like population (Pop_{it}), the share of trade in the country's GDP ($Trade_{it}$) and life expectancy at birth ($Life_{it}$), used as a proxy of health, is introduced into Equation (7). We instrument RD_{it} with other proxies of technological progress, such as per capita patents ($Patent_{it}$) and energy industrial consumption (Eng_{it}).[13] ω_i is the unobserved region-specific effects and ξ_{it} is the error term. A positive effect of innovation on GDP is verified if $\delta_1 > 0$.

4 The data

The EKC hypothesis is checked for three different air pollutants; CO, NMVOCs and SO_x. They are all expressed as emissions level. These data are available at regional level for the first time on the ISPRA (Italian Institute for Environmental Protection and Research) website (February 2010) for the years 1990, 1995, 2000 and 2005. We calculate per capita emissions levels for each pollutant as a dependent variable in the functional forms (6). Population data are freely available in the DEMO database from ISTAT, the Italian National Statistics Institute.

Variables y_i and g_i are calculated following BRADFORD ET AL. (2005).[14] In this paper, following MAGNANI (2000) and DINDA (2004),[15] technological progress is proxied by spending on R&D in the years 1990-2005, indicated as RD_{it}. In equation (6), T_i is the average degree of innovative spending in the i-th region. Per capita income and technological progress data are downloaded from Eurostat Regional Statistics.

We estimate Equations (6) considering different control variables such as EDU_{it}, the Gross Percentage of Secondary School Enrollment, retrieved from the ISTAT Territorial Indicator database. The school enrollment rate is a good proxy of human capital and is used both in the growth literature (as in CASELLI ET AL. 1998, DOWRICK & ROGERS,

[13] BIANCHI ET AL. (2009) check the robustness of their estimation through a set of technological proxies such as electric power consumption (Kwh per capita), electric power transmission and distribution (as a percentage of output), number of personal computers (per thousand people), number of telephone mainlines (per thousand people).

[14] We indicate as Y_i^1 the average per capita income in country i over the period 1990 to 1993 and as Y_i^2 the average over the period 2002 to 2005. The average growth rate g_i is derived from this condition $Y_i^2 = Y_i^1 exp(10g_i)$, while $y_i = Y_i^1 exp(5g_i)$ is the interpolated income at in the sample mid-point.

[15] On this point see also SMULDERS ET AL. (2011).

2002 and Bianchi et al., 2009) and in EKC studies (see for example Gangadharan & Valenzuela, 2001 and Orubu & Omotor, 2011). We extend this basic model in order to test the significance of international trade, given that trade plays a crucial role in EKC literature, as well as in the Italian economy. In fact, international trade is one of the most important factors in explaining the downward sloping portion of the EKC. This is principally due to 'the pollution heaven hypothesis', i.e. the transformation of advanced economies that '*cease to produce certain pollution intensive goods and begin instead to import these from other countries with less restrictive environmental protection laws*' (Grossman & Krueger, 1995).

In many papers the openness of a country is measured as the sum of total exports and imports divided by GDP. Suri & Chapman (1998) point out that this is a poor way of defining trade, because it does not capture the impact of differential competition between imports and exports. So following Suri & Chapman, we introduce the two explanatory variables that best capture the effect of cross-country movements of polluting goods, defined as X_{it} and M_{it}. X_{it} and M_{it} are the share of manufacturing goods exports and imports in manufacturing value added; their expected signs are positive and negative respectively. All trade data are freely available on the database Coeweb, supplied by ISTAT. Finally, as in Suri & Chapman, we also consider a measure of the structural transformation of the economy, MFG_{it}, computed as the ratio between manufacturing value added and total regional GDP; its expected sign is positive.

Per capita income used to test the existence of the EKC in Italian regions is obtained by Equation (7). In this case, the control variables are the ratio of gross investment on GDP (S_{it}), the population level (Pop_{it}), the ratio between the sum of total export and import and GDP ($Trade_{it}$) and finally, life expectancy at birth ($Life_{it}$).[16] All these variables influence positively the economic growth and they are added incrementally in the equation.

Descriptive statistics of the data related to Equation (6) and (7) are reported separately in Tables 2 and 3 respectively. In particular, the correlation matrix among the variables which will be used in the regressions analysis suggests the positive relationship between RD_{it} and Y_{it}. Y_{it} is also positively correlated with EDU_{it}, with MFG_{it} and all the variables related to trade (X_{it}, M_{it} and $Trade_{it}$). In addition, Y_{it} is negatively correlated with the three pollutants considered and Eng_{it}.[17] This supports the idea of an inverse relationship between growth and environmental stress. Finally, the data in Table 2 show a clear relationship (a negative and positive correlation) between RD_{it} and the variables chosen as its instruments, Eng_{it} and $Patents_{it}$.

Tables 2 and 3 near here

[16] Leitão (2010) follows a similar approach.

[17] Energy consumption is occasionally used in the literature as a proxy of pollution. See, for example, Suri & Chapman (1998).

5 Econometric Results

In this section, we present the results obtained from the estimations of Equations (6) and (7). Both equations were estimated with the inclusion of both fixed and random effects as in Bradford et al. (2005) and Leitão (2010). To save space, random effects estimations are not reported in the tables. They are available under request by the author.

Table 4 near here

Table 4 shows the estimates of Equation (7). Innovation is proxied by RD_{it}, the public spending on *R&D* which is instrumented using Two-Stage Least Squares (2SLS). 2SLS is an econometric technique particularly appropriate when some of the right-hand side variables are correlated with disturbances, as for example when they are endogenously determined variables, or difficult to measure accurately. Instruments list is composed by the patent applications to the European Patent Office ($Patent_{it}$) and energy intensity in the industry (Eng_{it}). Real per capita income is a function of innovation and of the ratio of gross investment on GDP (RD_{it} and S_{it} respectively) in Model (a), while Models (b) to (d) add population (Pop_{it}), the ratio of international trade on GDP ($Trade_{it}$) and life expectancy at birth ($Life_{it}$). The hypothesis $\delta_1 > 0$ is verified in all the models in Table 4, in fact the coefficient of technological progress is positive and statistically significant at 1 per cent level. The same conclusion is found for S_{it}, which is highly significant and with a positive sign in all the models; $Trade_{it}$ and $Life_{it}$ are also found to be significant at 1 per cent level and positive in the last two models shown in Table 4. Pop_{it} is not statistically significant in Models (b) to (d). The Anderson canonical correlations test indicates that the model is identified in all the cases. Sargan's test does not reject the null hypothesis at the conventional critical value, so the instruments chosen are proved to be statistically valid. Furthermore, the first stage F statistic indicates the exclusion of 'weak' instruments;[18] the Cragg-Donald statistic, the Anderson-Rubin Wald test and the Stock-Wright LM S statistic formally confirm this finding. We also performed a test about the endogeneity of RD_{it}.

Finally, Hausman's test indicates that fixed effects are the appropriate specification in Models (c) and (d), while random effects are preferred in Models (a) and (b). Bradford et al. (2005) and Leitão (2010) state that fixed effects may be more appropriate than random effects, because they capture the correlation between specific unobserved effects and the explanatory variables. Furthermore, regional unobserved characteristics are correlated with income. Given this fact and the higher value of R^2, we choose Model (d) to fit per capita GDP to be used in Equation (6).

Table 5 near here

[18] The instruments are 'weak' if the first stage F statistic is less then 10. See also Wooldridge (2002), Chapter 5.

The new EKC specification proposed by Bradford et al. (2005) overcomes some of the mis-specification problems related to the use of non-linear transformations of unit-root variables (like per capita GDP), which traditionally affect the specification of the EKC. Table 5 reports some descriptive statistics of fitted values of per capita income from Equation (7), Model (d), and some panel unit-root tests. These tests indicate the presence of a unit-root in the estimated variable.[19] This further justifies the decision to use Equation (6) to test the existence of the EKC.

We estimate Equation (6) for CO_{it}, $NMVOCS_{it}$ and SOX_{it}.[20] Tables 6, 7 and 8 report the estimations with the inclusion of fixed effects.

Tables 6, 7 and 8 near here

For all the pollutants, a basic model is estimated adding the school-enrollment rate EDU_{it} as control variable (Column a for each tables). EDU_{it} is highly significant and with the expected negative sign. Columns (b) to (d) also show the share of manufacturing goods exports and imports in manufacturing value added (X_{it} and M_{it} respectively) and finally the ratio between manufacturing value added and total regional GDP (MFG_{it}). In the case of CO_{it} and $NMVOCS_{it}$, X_{it}, M_{it} and MFG_{it} exhibit the signs predicted by the literature (see Suri & Chapman, 1998), but only X_{it} is significant (Columns c and d). On the other hand, in the case of SOX_{it}, only X_{it} and M_{it} present the sign predicted by the literature; none of these variables are significant at the conventional critical value.

Tables 6, 7 and 8 provide two different results. First of all, the hypothesis of an inverse-U-shaped relationship between per capita income and environmental degradation is verified for the three pollutants; coefficient β_0 is negative and significant in all the estimates as Bradford et al. (2005) indicate. As far as we know, EKC studies for Italy are rare; Cialani (2007) only investigates this framework for CO_2 using a time series approach, but her results indicate an increasing linear relation between the pollutant and per capita income. This is the first time in the literature that the EKC has been studied in the twenty Italian regions for CO, NMVOCs and SO_x. In general, in the single country EKC literature, heterogeneous results for CO are obtained by Carson et al. (1997) and Khanna (2002) in the USA, while Roca et al. (2001) cannot observe any clear linkage between per capita GDP and NMVOCs in Spain. The EKC for SO_x is however identified

[19] Note that only Levin et al. (2002) reject the null hypothesis of the presence of a unit root. All the other tests reported in Table 5 validate the nonstationary behaviour of per capita income used in the estimation of the EKC according to Equation (6).

[20] *R&D* data are not available for the years 1990 to 1994. For this reason, fitted values of per capita income data are missing for these years. In order to compute y_i and g_i according to the indications of Bradford et al. (2005) summarized in Section 4, we compute the mean estimated errors $\bar{\zeta_i}$ as the mean of the difference between fitted and observed per capita income as follow $\bar{\zeta_i} = \frac{1}{10}\sum(\hat{y_{it}} - y_{it})$ for all $i = 1, ..., 20$ and for all $t = 1995, ..., 2005$. Thus we can replace the missing observations for the years 1990-94 according to the following equation: $\hat{y_{it}} = y_{it} + \bar{\zeta_i}$ for all $i = 1, ..., 20$ and $t = 1990, ..., 1994$. Finally, in order to compute T_i, we note that *R&D* does not substantially vary for each region over time. For this reason, T_i is simply computed considering the data available.

in different papers as in List & Gallet (1999) and in Millimet et al. (2003) for the 50 US States, in Roca et al. (2001) for Spain and in Fodha & Zaghdoud (2010) for Tunisia.[21]

Second, coefficient β_2 proves to be negative and significant in all three Tables 6, 7 and 8. This validates the hypothesis that the turning point of the EKC is an inverse function of innovation as in Equation 3. The more innovative a country (region), the lower its level of per capita income (the turning point of the EKC) that pollution begins to decrease. This phenomenon may be interpreted as a sort of 'environmental catching up'. This finding is in line with Chimeli & Braden (2005), who indicate the existence of a critical value of TFPs such that higher TFPs (and income) are associated with improvements in environmental quality.[22] Furthermore, the inclusion of country-specific characteristics likely correlated with income, such as technological progress, ensures unbiased and consistent estimates. Finally, as in Bradford et al. (2005), coefficient β_1 is positive and highly significant in Tables 6 and 7 and only in Columns (c) and (d) in Table 8.

In all the cases considered, Hausman's test rejects the null hypothesis in favor of fixed effects: this is in line with the findings of Bradford et al. (2005) and Leitão (2010).[23] In the last columns of Tables 6, 7 and 8 we report for each model the estimated values of λ_1 and λ_2 and their standard errors. The parameter λ_1 is positive and statistically different to zero in all the estimates. This confirms the positive sign of coefficient β_1. The inverse relationship between technological progress and the turning point indicated in Equation 3 is moreover confirmed by the sign of the parameter λ_2, which is negative and significant, with the exception of Columns (a) and (b) in Table 8.

6 Conclusions

In this paper we analyzed the existence of the EKC hypothesis for three air pollutants, CO, NMVOCs and SO_x, in a new dataset based on the Italian regions published by ISPRA (2010 edition). We use a new formulation of the EKC provided for the first time by Bradford et al. (2005) and recently extended by Leitão (2010), which overcomes some econometric problems related to the traditional functional form of the EKC. Like Leitão, who studies the influence of corruption in the EKC framework, we explicitly analyze the role of technological progress on the EKC and on its turning point, in line with the recent theoretical contributions of Andreoni & Levinson (2001), Chimeli & Braden (2005), Johansson & Kriström (2007) and more recently by Brock &

[21]For a more general survey see Stern 2004.

[22]Although with different approaches, Andreoni & Levinson (2001), Johansson & Kriström (2007), Brock & Taylor (2010) and Smulders et al. (2011) identify the technological progress as the key factor to obtain the EKC.

[23]Only in Table 7 Column (a), Hausman's test does not reject the null hypothesis at 10 per cent critical value.

Taylor (2010) and Smulders et al. (2011).

A methodology similar to Leitão (2010) is used. In particular, innovation influences the EKC directly and indirectly, given its close relationship with income. Given this close link between technological progress and income, a preliminary estimate of GDP is made in order to capture the influence of technological progress. Fitted values of per capita income are used for the estimation of the EKC.

Our results confirm the validity of the EKC in the Italian regions for the three air pollutants considered. Furthermore, in line with the theoretical findings, we find that technological progress is a relevant factor in the estimation of the EKC. In fact, our hypothesis about the influence of innovation on the EKC turning point is validated. This implies that a sort of 'environmental catching up' is verified: the more innovative a country (a region), the lower the level of per capita income at which pollution begins to decrease. This finding is in line with the simulation results of Chimeli & Braden (2005), who note that there is a critical value of TFPs such that higher TFPs are associated with better environmental quality. This result is also confirmed by the indirect estimations of the parameters that define the linkage between the turning point of the EKC and innovation. Finally, given the inclusion of country-specific characteristics likely correlated with income, the estimates are unbiased and consistent.

References

[1] Andreoni, J., Levinson, A., (2001). The Simple Analytics of the Environmental Kuznets Curve. *Journal of Public Economics*, 80:269-286.

[2] Akbostancı, E., Türüt-Aşik, S., Tunç, İ., (2009). The Relationship Between Income and Environment in Turkey: Is There an Environmental Kuznets Curve? *Energy Policy*, 37:861-867.

[3] Aldy, J.E., (2005). An Environmental Kuznets Curve Analysis of U.S. State-Level Carbon Dioxide Emissions. *The Journal of Environment and Development*, 14:48-72.

[4] Ang, J.,B., (2007). CO_2 emissions, energy consumption, and output in France. *Energy Policy*, 35:4772-4778.

[5] Bianchi, C., Calidori, F., Menegatti, M., (2009). Pitfalls in Estimating β-convergence by Means of Panel Data: an Empirical Test. *International Review of Economics*, 56:347-357.

[6] Bradford, D.F., Fender, R., Shore S.H., Wagner, M., (2005). The Environmental Kuznets Curve: Exploring a Fresh Specification. Contributions to Economic Analysis and Policy 4, No. 1, Article 5.

[7] Breitung, J., (2000). The Local Power of Some Unit Root Tests for Panel Data. In: Baltagi, B. (Ed.), *Advances in Econometrics, Nonstationary Panels, Panel Cointegration, and Dynamic Panels*, Vol.15. JAI Press, Amsterdam, 161178.

[8] Brock, W.A., Taylor, M.S., (2010). The Green Solow Model. *Journal of Economic Growth*, 15:127-153.

[9] Carson, R.T., Jeon, Y., McCubbin, D.R., (1997). The Relationship Between Air Pollution Emissions and Income: US Data. *Environment and Development Economics*, 2:433-450.

[10] Caselli, F., Esquivel, G., Lefort, F., (1996). Reopening the convergence debate: a new look at cross-country growth empirics. *Journal of Economic Growth*, 1:363-389.

[11] Chimeli, A.B., Braden, J.B., (2005). Total Factor Productivity and the Environmental Kuznets Curve. *Journal of Environmental Economics and Management*, 49:366-380.

[12] Cialani, C., (2007). Economic Growth and Environmental Quality: An Econometric and a Decomposition Analysis. *Management of Environmental Quality: An International Journal*, 18:568-577.

[13] Choi, I., (2001). Unit Root Tests for Panel Data. *Journal of International Money and Finance*, 20:249-272.

[14] Dinda, S., (2004). Environmental Kuznets Curve Hypothesis: a Survey. *Ecological Economics*, 49:431-455.

[15] Dowrick, S., Rogers, M., (2002). Classical and technological convergence: beyond the Solow-Swan growth model. *Oxford Economic Papers*, 54:369-385.

[16] European Commission, (1999). *Towards environmental Pressure Indicators for the EU*. (Eds.) European Commission/Eurostat, Luxembourg.

[17] Fodha, M., Zaghdoud, O., (2010). Economic Growth and Pollutant Emissions in Tunisia: An Empirical Analysis of the Environmental Kuznets Curve. *Energy Policy*, 38:1150-1156.

[18] Friedl, B., Getzner, M., (2003). Determinants of CO_2 Emissions in a Small Open Economy. *Ecological Economics*, 45:133-148.

[19] Galeotti, M., Manera, M., Lanza, A., (2009). On the Robustness of Robustness Checks of the Environmental Kuznets Curve Hypothesis. *Environmental and Resource Economics*, 42:551-574.

[20] Gangadharan, L., Valenzuela, Ma.R., (2001). Interrelationships Between Income, Health and the Environment: Extending the Environmental Kuznets Curve Hypothesis. *Ecological Economics*, 36:513-531.

[21] Grossman, G.M., Krueger, A.B., (1991). Environmental Impacts of the North American Free Trade Agreement. *NBER Working paper*, 3914.

[22] Grossman, G.M., Krueger, A.B., (1995). Economic Growth and the Environment. *Quarterly Journal of Economics*, 110:353-377.

[23] Hadri, K., (2000). Testing for Stationarity in Heterogeneous Panel Data. *Econometrics Journal*, 3:148-161.

[24] He, J., Richard, P., (2010). Environmental Kuznets Curve for CO_2 in Canada. *Ecological Economics*, 69:1083-1093.

[25] Im, K.S., Pesaran, M.H., Shin, Y., (2003). Testing for Unit Roots in Heterogeneous Panels. *Journal of Econometrics*, 115:53-74.

[26] Islam, N., (1995). Growth Empirics: A Panel Data Approach. *The Quarterly Journal of Economics*, 110:1127-1170.

[27] Iwata, H., Okada, K., Samreth, S., (2010). Empirical Study on the Environmental Kuznets Curve for CO_2 in France: The Role of Nuclear Energy. *Energy Policy*, 38:4057-4063.

[28] Jalil, A., Mahmud, S.F., (2009). Environmental Kuznets Curve for CO_2 Emissions: A Cointegration Analysis for China. *Energy Policy*, 37:5167-5172.

[29] Johansson, P.O., Kriström, B., (2007). On a clear day you might see an environmental Kuznets curve. *Environmental and Resource Economics* 37:77-90.

[30] Kahn, M.E., (1998). A Household Level Environmental Kuznets Curve. *Economics Letters*, 59:269-273.

[31] Khanna, N., (2002). The Income Elasticity of Non-Point Source Air Pollutants: Revisiting the Environmental Kuznets Curve. *Economics Letters*, 77:387-392.

[32] Kuznets, S., (1955). Economic Growth and Income Inequality. *American Economic Review*, 45:1-28.

[33] Lekakis, J.N., (2000). Environment and Development in a Southern European Country: Which Environmental Kuznets Curves? *Journal of Environmental Planning and Management*, 43:139-153.

[34] Leitão, A., (2010). Corruption and the Environmental Kuznets Curve: Empirical Evidence for Sulfur. *Ecological Economics*, 69:2191-2201.

[35] Levin, A., Lin, C.F., Chu, C., (2002). Unit Root Tests in Panel Data: Asymptotic and Finite-Sample Properties. *Journal of Econometrics*, 108:1-24.

[36] List, J.A., Gallet, C.A., (1999). The Environmental Kuznets Curve: Does One Size Fit All? *Ecological Economics*, 31:409-423.

[37] Maddala, G.S., Wu, S., (1999). A Comparative Study of Unit Root Tests with Panel Data and a New Simple Test. *Oxford Bulletin of Economics and Statistics*, 61:631-652.

[38] Magnani, E., (2000). The Environmental Kuznets Curve, Environmental Protection Policy and Income Distribution. *Ecological Economics*, 32:431-443.

[39] Millimet, D.L., List, J.A., Stengos, T., (2003). The Environmental Kuznets Curve: Real Progress or Misspecified Models? *The Review of Economics and Statistics*, 85:1038-1047.

[40] Nasir, M., Rehman, F.U., (2011). Environmental Kuznets Curve for carbon emissions in Pakistan: An empirical investigation. *Energy Policy*, 39:1857-1864.

[41] Orubu, O.C., Omotor, D.G., (2011). Environmental Quality and Economic Growth: Searching for Environmental Kuznets Curves for Air and Water Pollutants in Africa. *Energy Policy*, 39:4178-4188.

[42] Panayotou, T., (1993). Empirical Tests and Policy Analysis of Environmental Degradation at Different Stages of Economic Development. *ILO, Technology and Employment Programme*, Geneva.

[43] Panayotou, T., (1997). Demystifying the Environmental Kuznets Curve: Turning a Black Box into a Policy Tool. *Environmental and Development Economics*, 2:469-484.

[44] Roca, J., Padilla, E., Farrè, M., Galletto, V., (2001). Economic Growth and Atmospheric Pollution in Spain: Discussing the Environmental Kuznets Curve Hypothesis. *Ecological Economics*, 39:85-99.

[45] Selden, T.M., Song, D., (1994). Environmental quality and development: is there a Kuznets Curve for air pollution emissions? *Journal of Environmental Economics and Management* 27:147-162.

[46] Shafik, N., Bandyopadhyay, S., (1992). Economic Growth and Environmental Quality: Time Series and Cross-Country Evidence. *Background Paper for the World Development Report*. The World Bank, Washington, DC.

[47] Smulders, S., Bretschger, L., Egli, H., (2011). Economic Growth and the Diffusion of Clean Technologies: Explaining Environmental Kuznets Curves. *Environmental and Resource Economics* 49:79-99.

[48] Stern, D.I., (1998). Progress on the Environmental Kuznets Curve? *Environment and Development Economics*, 3:173-196.

[49] Stern, D.I., (2004). The Rise and Fall of the Environmental Kuznets Curve. *World Development*, 32:1419-1439.

[50] Stock, J.H., Yogo, M., (2005). Testing for Weak Instruments in Linear IV Regression. In D.W.K. Andrews and J.H. Stock, eds. *Identification and Inference for Econometric Models: Essays in Honor of Thomas Rothenberg*. Cambridge: Cambridge University Press, 80-108.

[51] Suri, V., Chapman, D., (1998). Economic Growth, Trade and the Environment: Implications for the Environmental Kuznets Curve. *Ecological Economics*, 25:195-208.

[52] Vincent, J.R., (1997). Testing for Environmental Kuznets Curves Within a Developing Country. *Environment and Development Economics*, 2:417-431.

[53] Wooldridge, J.M., (2002). Econometric Analysis of Cross Section and Panel Data. Cambridge, MA: MIT Press.

Table 1: Single country EKC studies

Author(s)	Country	Pollutant(s)	Curve shaped
Carson *et al.* (1997) *(Environ Dev Econ)*	US 50 States	Greenhouse gases Air toxics CO NO_x SO_2 Volatile Organic Carbon (VOC) PM_{10}	Linear (decreasing) Linear (decreasing) Linear (decreasing) Linear (decreasing) Linear (decreasing) Linear (decreasing) Linear (decreasing)
Vincent (1997) *(Environ Dev Econ)*	Malaysia	Total Suspended Particulates (TSP) Biochemical Oxygen Demand (BOD) Chemical Oxygen Demand (COD) Ammoniac Nitrogen pH Suspended Solids in rivers	N-shaped n.a. n.a. Increasing (linear) Increasing (linear) n.a.
Kahn (1998) *(Econ Lett)*	California	Vehicle hydrocarbon emissions	EKC
List and Gallet (1999) *(Ecol Econ)*	US States	NO_x SO_2	EKC EKC
Lekakis (2000) *(J Environ Plann Manag)*	Greece	Air pollution Agricultural pollution Fishery depletion Forest destruction	n.a. n.a. n.a. n.a.
Roca *et al.* (2001) *(Ecol Econ)*	Spain	CH_4 CO_2 N_2O NMVOCs NO_x SO_2	n.a. n.a. n.a. n.a. n.a. EKC
Khanna (2002) *(Econ Lett)*	US 50 States	CO NO_x O_3	n.a. U-shaped n.a.
Friedl and Getzner (2003) *(Ecol Econ)*	Austria	CO_2	N-shaped
Millimet *et al.* (2003) *(Rev Econ Stat)*	US 50 States	NO_x SO_2	EKC EKC
Aldy (2005) *(Environ Dev Econ)*	US 50 States	CO_2	EKC
Ang (2007) *(Energ Pol)*	France	CO_2	EKC
Cialani (2007) *(Manag Environ Qual Int J)*	Italy	CO_2	Linear (increasing)
Akbostancı *et al.* (2009) *(Energ Pol)*	Turkey	CO_2 PM_{10} SO_2	Linear (increasing) N-shaped N-shaped
Jalil and Mahmud (2009) *(Energ Pol)*	China	CO_2	EKC
Fodha and Zaghdoud (2010) *(Energ Pol)*	Tunisia	CO_2 SO_2	Linear (increasing) EKC
He and Richard (2010) *(Ecol Econ)*	Canada	CO_2	Linear (increasing)
Iwata *et al.* (2010) *(Energ Pol)*	France	CO_2	EKC
Nasir and Rehman (2011) *(Energ Pol)*	Pakistan	CO_2	EKC

Table 2: Descriptive statistics of the variables in Equation (6)

	CO_{it}	EDU_{it}	$NMVOCS_{it}$	M_{it}	MFG_{it}	RD_{it}	SOX_{it}	X_{it}	Y_{it}
Mean	95.14	88.48	33.97	55.84	29.26	0.85	15.77	62.87	17823.99
Std. Dev.	36.83	7.99	8.23	36.55	21.21	0.43	17.15	36.73	5911.25
Obs	80	220	80	300	320	220	80	300	320
Correlation Matrix									
	CO_{it}	EDU_{it}	$NMVOCS_{it}$	M_{it}	MFG_{it}	RD_{it}	SOX_{it}	X_{it}	Y_{it}
CO_{it}	1								
EDU_{it}	-0.33	1							
$NMVOCS_{it}$	0.42	-0.20	1						
M_{it}	-0.19	-0.19	-0.13	1					
MFG_{it}	-0.12	-0.42	0.10	0.43	1				
RD_{it}	-0.05	0.29	-0.16	0.36	-0.16	1			
SOX_{it}	0.55	-0.06	0.51	0.04	-0.14	0.01	1		
X_{it}	-0.22	-0.16	0.05	0.56	0.79	0.19	-0.05	1	
Y_{it}	-0.62	0.29	-0.35	0.47	0.35	0.40	-0.24	0.64	1

Notes: All the variables are in level.

Table 3: Descriptive statistics of the variables in Equation (7)

	Eng_{it}	$Life_{it}$	$Patent_{it}$	Pop_{it}	RD_{it}	S_{it}	$Trade_{it}$	Y_{it}
Mean	160.87	75.24	46.53	2,852,604	0.85	21.47	28.07	17823.99
Std. Dev.	90.94	17.08	43.99	2,248,274	0.43	3.43	15.11	5911.25
Obs	320	320	320	320	220	320	320	320
Correlation Matrix								
	Eng_{it}	$Life_{it}$	$Patent_{it}$	Pop_{it}	RD_{it}	S_{it}	$Trade_{it}$	Y_{it}
Eng_{it}	1							
$Life_{it}$	0.14	1						
$Patent_{it}$	-0.29	-0.20	1					
Pop_{it}	-0.11	-0.18	0.33	1				
RD_{it}	-0.17	0.15	0.39	0.45	1			
S_{it}	0.09	-0.34	-0.11	-0.53	0.47	1		
$Trade_{it}$	-0.21	0.01	0.82	0.45	0.42	-0.26	1	
Y_{it}	-0.36	-0.36	0.82	0.18	0.39	-0.05	0.67	1

Notes: All the variables are in level.

Table 4: Estimation results of Equation (7) - Fixed Effects

Dependent variable: Y_{it}	(a)	(b)	(c)	(d)
RD_{it}	0.32 (0.07)***	0.31 (0.08)***	0.25 (0.08)***	0.21 (0.07)***
S_{it}	0.91 (0.14)***	0.89 (0.14)***	0.80 (0.12)***	0.60 (0.11)***
Pop_{it}	-	0.63 (0.56)	0.91 (0.53)*	-0.29 (0.49)
$Trade_{it}$	-	-	0.25 (0.06)***	0.19 (0.06)***
$Life_{it}$	-	-	-	2.37 (0.34)***
R^2	0.41	0.42	0.52	0.64
Anderson canonical correlation LM statistic p-value	41.21 0.00	38.45 0.00	34.53 0.00	34.29 0.00
Cragg-Donald Wald F statistic	25.57	23.32	20.35	20.08
First stage F statistic p-value	27.22 0.00	20.61 0.00	21.37 0.00	17.72 0.00
Anderson-Rubin Wald test (χ^2) p-value	24.24 0.00	22.39 0.00	15.48 0.00	12.99 0.00
Stock-Wright LM S statistic (χ^2) p-value	21.62 0.00	20.14 0.00	14.36 0.00	12.20 0.00
Sargan's statistic p-value	2.10 0.15	3.17 0.07	2.37 0.12	1.55 0.21
Endogeneity test p-value	7.29 0.01	6.35 0.01	6.68 0.01	5.53 0.01
Hausman's test p-value	0.52 0.77	1.87 0.60	13.76 0.01	18.70 0.00
Number of observations	220	220	220	220

Notes: All the variables are in log; Asymptotic standard errors are reported in brackets; A *(**)[***] indicates significance at 10(5)[1] per cent level; RD_{it} is instrumented with Eng_{it} and $Patents_{it}$; The Anderson canonical correlations test is a likelihood-ratio test of whether the equation is identified. Under the null of underidentification, the statistic is distributed as χ^2 with degrees of freedom equal to $L - R + 1$ where L and R are the number of instruments and regressors respectively. A rejection of the null indicates that the model is identified; The Cragg-Donald statistic is a test for weak identification, which arises when the excluded instruments are weakly correlated with the endogenous regressors. Critical values for single endogenous regressor are provided by Stock & Yogo (2005) as follow: 10, 15, 20, 25 per cent maximal IV size are 19.93, 11.59, 8.75, 7.25 respectively; Weak-instrument-robust inference is verified by the Anderson-Rubin Wald test and by the Stock-Wright LM S statistic. The null hypothesis of these two tests is the joint significance of endogenous regressors and the validity of the overidentifying restrictions. Both statistics are distributed as χ^2 with degrees of freedom equal to the number of excluded instruments; Sargan's test is a test of overidentifying restrictions. The joint null hypothesis is that the instruments are valid instruments; The endogeneity test (or 'GMM distance' or 'difference-in-Sargan' statistic) is a test of the exogeneity of one or more instruments. The null hypothesis is that endogenous variable can be treated as exogenous; Finally, Hausman's test is based on estimating the variance of the difference of the fixed and random effects estimators and it is distributed as χ^2 with degrees of freedom equal to the number of regressors.

Table 5: Descriptive Statistics and Panel Unit Root Tests for fitted per capita income

Descriptive Statistics	
Mean	9.91
Std. Dev.	2.23
Obs	220
Panel Unit Root tests	
Levin *et al.* (2002)	-3.53
	(0.00)
Breitung (2000)	1.25
	(0.89)
Im *et al.* (2003)	0.36
	(0.64)
ADF (1999)	319.16
	(0.81)
PP (2001)	263.59
	(0.95)
Hadri (2000)	807.84
	(0.00)

Notes: Fitted values of per capita income are in log; P-values are reported in brackets; Levin et al. (2002) and Breitung (2000) are t-statistics which check the presence of a common unit-root process; Im et al. (2003) W-statistic, ADF (Maddala & Wu, 1999) and PP (Choi, 2001) Fisher Chi-square statistics assumes that the series has an individual unit-root under the null hypothesis; Finally, Hadri (2000) Z-statistics verifies the null hypothesis of no unit common root process.

Table 6: Estimation results of Equation (6) for CO_{it} - Fixed Effects

Dependent variable: CO_{it}	(a)	(b)	(c)	(d)
Constant	16.19	16.66	16.46	13.63
	(2.19)***	(2.15)***	(2.17)***	(2.86)***
$y_i g_i t$	-0.88	-0.95	-0.97	-0.89
	(0.24)***	(0.24)***	(0.24)***	(0.24)***
$g_i t$	8.18	8.87	9.05	8.32
	(2.51)***	(2.49)***	(2.50)***	(2.51)***
$T_i g_i t$	-0.64	-0.68	-0.66	-0.54
	(0.16)***	(0.16)***	(0.16)***	(0.18)***
EDU_{it}	-2.58	-2.87	-2.78	-2.58
	(0.50)***	(0.52)***	(0.53)***	(0.54)***
X_{it}	-	0.19	0.28	0.29
		(0.12)	(0.15)*	(0.15)*
M_{it}	-	-	-0.13	-0.06
			(0.15)	(0.16)
MFG_{it}	-	-	-	0.52
				(0.35)
R^2	0.91	0.92	0.92	0.92
Hausman's test	17.55	60.04	42.40	23.57
p-value	0.00	0.00	0.00	0.00
λ_1	9.27	9.32	9.37	9.33
	(0.33)***	(0.29)***	(0.28)***	(0.31)***
λ_2	-0.73	-0.72	-0.68	-0.61
	(0.24)***	(0.21)***	(0.21)***	(0.22)***

Notes: Asymptotic standard errors are reported in brackets; A *(**)[***] indicates significance at 10(5)[1] per cent level; Unlike to Leitão (2010), who uses all the explanatory variables in level with the exception of the dependent variable (transformed in logarithms), in this work $y_i g_i t$ and $T_i g_i t$ are computed considering the log trasformation of Y_{it} and RD_{it} respectively, while all the other variables are in log.

Table 7: Estimation results of Equation (6) for $NMVOCS_{it}$ - Fixed Effects

Dependent variable: $NMVOCS_{it}$	(a)	(b)	(c)	(d)
Constant	12.76	13.38	13.21	10.30
	(1.82)***	(1.69)***	(1.70)***	(2.19)***
$y_i g_i t$	-0.55	-0.64	-0.65	-0.58
	(0.20)**	(0.19)***	(0.19)***	(0.19)***
$g_i t$	5.28	6.17	6.32	5.56
	(2.10)**	(1.95)***	(1.96)***	(1.92)***
$T_i g_i t$	-0.37	-0.42	-0.40	-0.28
	(0.14)**	(0.13)***	(0.13)***	(0.14)**
EDU_{it}	-2.06	-2.43	-2.37	-2.17
	(0.42)***	(0.41)***	(0.42)***	(0.41)***
X_{it}	-	0.25	0.32	0.33
		(0.09)***	(0.12)**	(0.11)***
M_{it}	-	-	-0.11	-0.03
			(0.12)	(0.12)
MFG_{it}	-	-	-	0.54
				(0.26)*
R^2	0.85	0.87	0.88	0.89
Hausman's test	8.17	32.73	27.26	29.46
p-value	0.08	0.00	0.00	0.00
λ_1	9.56	9.60	9.67	9.63
	(0.36)***	(0.27)***	(0.26)***	(0.29)***
λ_2	-0.67	-0.65	-0.61	-0.49
	(0.30)**	(0.23)***	(0.23)***	(0.24)**

Notes: Asymptotic standard errors are reported in brackets; A *(**)[***] indicates significance at 10(5)[1] per cent level; Unlike to Leitão (2010), who uses all the explanatory variables in level with the exception of the dependent variable (transformed in logarithms), in this work $y_i g_i t$ and $T_i g_i t$ are computed considering the log trasformation of Y_{it} and RD_{it} respectively, while all the other variables are in log.

Table 8: Estimation results of Equation (6) for SOX_{it} - Fixed Effects

Dependent variable: SOX_{it}	(a)	(b)	(c)	(d)
Constant	17.39	17.89	16.84	22.20
	(6.49)**	(6.61)***	(6.54)**	(8.79)**
$y_i g_i t$	-1.27	-1.34	-1.41	-1.55
	(0.72)*	(0.74)*	(0.73)*	(0.75)**
$g_i t$	11.10	11.82	12.77	14.16
	(7.46)	(7.64)	(7.54)*	(7.70)*
$T_i g_i t$	-2.30	-2.34	-2.21	-2.43
	(0.48)***	(0.49)***	(0.49)***	(0.55)***
EDU_{it}	-3.33	-3.63	-3.20	-3.57
	(1.50)**	(1.60)**	(1.60)*	(1.66)**
X_{it}	-	0.21	0.63	0.62
		(0.36)	(0.46)	(0.46)
M_{it}	-	-	-0.68	-0.81
			(0.46)	(0.49)
MFG_{it}	-	-	-	-0.98
				(1.07)
R^2	0.75	0.76	0.77	0.78
Hausman's test	17.49	14.73	35.05	30.15
p-value	0.00	0.01	0.00	0.00
λ_1	8.75	8.81	9.04	9.12
	(0.95)***	(0.88)***	(0.73)***	(0.64)***
λ_2	-1.81	-1.75	-1.56	-1.56
	(1.01)	(0.93)	(0.79)*	(0.72)**

Notes: Asymptotic standard errors are reported in brackets; A *(**)[***] indicates significance at 10(5)[1] per cent level; Unlike to Leitão (2010), who uses all the explanatory variables in level with the exception of the dependent variable (transformed in logarithms), in this work $y_i g_i t$ and $T_i g_i t$ are computed considering the log trasformation of Y_{it} and RD_{it} respectively, while all the other variables are in log.