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Contact to corresponding author: Javier Sánchez García, jsg608@ual.es

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Javier Sánchez García
University of Almeria, Spain
orcid.org/0000-0002-5907-0340

Emilio Galdeano Gómez
University of Almeria, Spain
orcid.org/0000-0001-5414-4331

What drives the preferences for cleaner energy? Parametrizing the elasticities of environmental quality demand for greenhouse gases

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Abstract

Research background: The heterogeneity in the factors that affect demand for environmental quality implicates a diverse set of policies and actions aimed at achieving cleaner production to address the challenges posed by pollution and damage to the natural environment. Even though this topic has been widely addressed, mainly from the traditional perspective of the Environmental Kuznets Curves hypothesis (EKC), it has been assumed that the environment is a luxury good with an income elasticity greater than unity. However, it has recently been

recognized that the relationship between income and demand for cleaner energy may be more complex and that further inquiry may be needed for a better understanding.
Purpose of the article: This research work, employing a panel of European countries, offers direct explicit parameters for the elasticity of income-environmental quality demand for Greenhouse Gases (GHG), as well as its relationship with other important factors. It provides quantitative novel insights into the complex relationship between income and the preferences for cleaner energy.
Methods: A hierarchical regression equations approach is used to analyze the evolution of the elasticity of income-environmental quality demand with the inclusion of further co-variates that are relevant for the preferences side of the EKC, such as consumption, R+D investment and BERD (Business Enterprise Research and Development). The data for the empirical study comes from a panel of 16 European countries for the period from 2010 to 2020.
Findings & value added: The results show robust evidence that the elasticity of environmental quality demand, which although positive and significant, does not exceed one. To obtain an elasticity above unity, two more variables are needed, namely the R+D expenditure of business enterprises and the exposure of citizens to air pollution. These two factors have a similar or even higher effect on the preferences of agents for cleaner energy, which also means that the preferences of the citizens are endogenous to technological development. At the theoretical level, this work shows that the technological and preferences arguments are not substitute explanations of the EKC, but that technological development exerts a positive effect on the preferences of inhabitants, whose demand for environmental quality is heavily conditioned by their capabilities to see pollution, even more than by their income level. This also means that public policies directed to improve environmental awareness should be directed first towards those regions where the exposure of the citizens to pollution is lower.

Introduction

Achieving better environmental quality has become one of the objectives of many societies and macroeconomic policies at a national and international scale in recent decades, and most recently it constitutes a priority of the Sustainable Development Goals (SDG). While pollution and environmental damage are global problems, the demand for their reduction is not homogeneous and, in many cases, depends on economic and social context, a topic that has been widely analyzed by the Environmental Kuznets Curves (EKC) hypothesis (Grossman & Krueger, 1995; Panayotou, 1997; Pata & Samour, 2022; Tenaw & Beyene, 2021; Yang *et al*., 2022; Hipólito Leal & Cardoso-Marques, 2022).

According to this hypothesis, the specific conditions under which measures against pollution tend to be adopted are primarily related to the economic development of a country or region. Some of the aspects studied in this regard include explanatory models of the income-environmental quality relationship (Khanna & Plassmann, 2004), the transformations of production structures and several effects (scale, composition and technological effects) of economic progress on the environment (Barrett & Graddy, 2000; Álvarez-Herranz *et al.*, 2017), international trade (Arrow *et al.*, 1995; Copeland & Taylor, 2004), inequality in income distribution (Blampied, 2021), the structure of employment and unemployment (Ohler, 2015), education (Shafiullah *et al.*, 2021) and the role of institutions (Hu *et al.*, 2022). However, among this set of explanatory variables, the income elasticity of environmental quality demand has proven to be, and still is, one of the main and easiest explanations of the slope of the EKC (Zilio, 2012, Blampied, 2021). In addition, Khanna and Plassmann (2004), as well as Figueroa and Pasten (2015), highlight that most analyses in this line show that technological and structural changes in general, and changes in environmental and commercial policies (for instance, as a result of consumer pressure on the institutional framework), are considered simply by the means through which changes in income elasticity translate into changes in levels of pollution.

Nevertheless, if societies that have reached a certain level of development increase their willingness to pay for environmental goods and services in a higher proportion than the growth of their income, there is an implicit assumption that the income elasticity of environmental quality demand is higher than one (Dinda, 2004; Barbier *et al.*, 2017). This elasticity is, therefore, the most common explanation for the shape of the EKC. It measures how much a household's willingness to pay for a cleaner environment increases (decreases) as a response to an increase (decrease) in income. Because the willingness to pay is a latent variable, this elasticity is usually restricted to a theoretical perspective and is based on assumptions, with a lack of empirical evidence about its value.

The argument then rests on the assumption that environmental goods may be classified as luxury goods, which has not been conclusively proven in empirical studies. For instance, take the case of an economic sector with relatively low income, situated in a rural area or directly dependent on natural resources, where individuals do not need to be rich to demand environmental improvement; income level would affect their payment capacities, but not their willingness to pay (Ekins & Speck, 2000; Barbier *et al.*, 2017). In addition, as Khanna and Plassmann (2004) and Dinda (2004) mention, if the objective is to implement adequate environmental policy, it is necessary to separately identify the preferences (demand-side) and other supply-side factors, mainly technological, which influence the income-pollution binomial.

Therefore, the demand for environmental quality results in a complex issue, one that is not only dependent on income (Pasten & Figueroa, 2012; Fouquet, 2014) and which requires more in-depth empirical study. The present study seeks to advance in this regard by analyzing a multi-country panel dataset of several European countries. An empirical model is then developed to determine the impact of income, employment, technological progress, and other factors (e.g., taxes, prices, the exposure to air pollution, etc.) on changes in the demand for environmental quality. To achieve robustness and control for variations, the hierarchical regression method is employed.

Theoretically, if preferences driven by income are enough to derive an EKC, this would translate as an elasticity of income-environmental quality demand higher than one (ϵY,G > 1) (Dinda, 2004). Empirically, this means that the estimates of this parameter are higher than one ($\hat{\epsilon}_{Y,G}$> 1), or equivalently, that the $\hat{\beta}$ of the econometric models for income (Y) as an independent variable and environmental quality demand for GHG (G) as a dependent variable, are higher than one, that is, $\hat{\beta}_{Y,G}$ > 1. If the estimates are robust, they must be above one across all or the majority of the hierarchical models.

The main purpose of this paper is, therefore, to parametrize the elasticity of income-environmental quality demand, offering empirical evidence about the value of this important magnitude, which appears recurrently in theoretical works as the main driver of the EKC. More specifically, this paper contributes to this research line by providing: (i) An analysis of demand elasticities of several variables explored in the literature, or still unexplored, such as citizen exposure to air pollution, in order to provide a more complete representation of the demand for environmental quality; (ii) Empirical evidence on whether the environment is a luxury good; (iii) Evidence of the implications of the preferences of households for the derivation of the EKC. According to economic theory, the latter two make it possible to corroborate whether the estimated elasticity with respect to income is higher than one.

The results show, firstly, that the other elasticities are more effective at explaining the demand for better air quality than the elasticity of income-environmental quality demand. Secondly, they show that the income elasticity of air quality demand is not higher than one. And thirdly, they demonstrate that the preferences of households (demand-side factors) are not enough to drive the EKC of Greenhouse Gases (GHG) on their own. Most noteworthy among the main results are the relevance of the technological factors and of the exposure of citizens to air pollution, and that certain factors are non-separable from income-environmental preferences to derive the EKC, as will be shown.

The remainder of the paper is structured as follows. Section 2 contains the background and literature review of the present study. Section 3 describes the data and methodology employed. Section 4, presents and discusses the results. Finally, Section 5 presents the main conclusions.

Literature review and theoretical motivation

The fact that natural resources, among other environmental goods and services, simultaneously function as consumption goods and production inputs, means that their consumption patterns in different stages of the production process depend on, given an initial endowment, their respective elasticities of supply and demand (Shafik & Bandyopadhyay, 1992; Frodyma *et al.*, 2022). For this reason, the income elasticity of environmental quality demand is one of the main and most simple arguments of the EKC hypothesis (Zilio, 2012; Hu *et al.*, 2022).

The basis for this argument lies in the idea that the poorest sectors of society will not demand environmental improvements until they cover their basic needs, such as nutrition, education or medical assistance. However, it is natural to think that once these individuals have reached a certain standard of living, they will give more value to environmental goods and services[1], elevating their willingness to pay for them in a larger proportion than the growth of their income (Roca, 2003; Barbier *et al.*, 2017). This implies that the income elasticity of environmental quality demand is higher than one, as Figure 1 shows. The said figure presents a monotonically increasing elasticity of income-environmental quality demand ($f(y)$). The y-axis reflects the value of the elasticity (ϵ), whilst the x-axis shows the value of the function f responsible for explaining ϵ, which of course depends on income (y). When $\epsilon < 1$, the curve of the EKC is linear and positive, so that higher income means higher pollution. However, when the turning point is

[1] At the same time, there tends to be an increase in pressure to undertake stricter environmental regulatory and protection measures.

reached (f'), i.e., when $\epsilon > 1$, the curve of the EKC bends down, more so the higher the value is of ϵ. In theoretical work, a scheme such as that of Figure 1 has been assumed to drive the EKC. However, Dinda (2004) mentions that key indicators of environmental degradation highlight that the elasticity may either be less than one or that it may be a complicated function that depends on something other than income alone.

In this context, since its empirical proposal by Grossman and Krueger (1995), a considerable number of theoretical models have been proposed to describe EKC (Andreoni & Levinson, 2001; Plassmann & Khanna, 2006; Jeffords & Thompson, 2019; Blampied, 2021; Ben Jebli *et al*., 2022), many which assume additive preferences. However, Figueroa and Pasten (2013) show that under non-additive preferences the income-pollution relationship may depend on the marginal elasticity of substitution between consumption and the environment, and not on the elasticity of the marginal utility of consumption. Also, these authors further demonstrate that those analytical models are captured by a theoretical preference-technology framework[2] that consists of two elasticities, namely the elasticities of preferences and technology with respect to environmental quality demand. As for the study by McConnell (1997), it derives theoretical models in which increasing pollution may occur with increasing income and preferences that imply a high-income elasticity of demand for environmental quality, while decreasing pollution may also occur with preferences related to a low value of said elasticity. In this framework, Pasten and Figueroa (2012) also offer a survey of the theoretical literature for the EKC and a general analytical framework to derive the EKC theoretically.

As for other research lines in the literature, empirical studies on the existence, characteristics and underlying structure of the EKC are abundant (Lin & Liscow, 2013; Lawell *et al*., 2018; Villanthenkodath *et al*., 2021; Hu *et al*., 2022; Hasan *et al*., 2022). However, empirical studies that delve into the foundations of the EKC by using the demand for environmental quality are scarce and date back many years. Yet, the work of Panayotou (1997) highlighted the need to know the underlying determinants of environmental

[2] The so-called technological effect (Grossman & Krueger, 1995) implies that a country with higher per-capita income has more resources to invest in clean energy R+D. In parallel, it is considered that this effect is accompanied by a composition effect (change in the economic structure) and a scale effect (increase in environmental damage because of economic growth). Thus, the evolution of the EKC is explained by the positive impact of the technological and composition effects exceeding the negative effect of the scale one (Balsalobre-Lorente & Álvarez-Herranz, 2016).

quality to offer policy considerations, revealing that the former may differ from income exclusively.

Indeed, the results on the income-environmental quality demand binomial are mixed. Khanna and Plassmann (2004) find that in the United States, one of the most developed countries in the world, high-income households have not yet reached the point at which their demand for environmental quality is high enough to turn the income-pollution relationship downwards for every pollutant that they analyze. Similarly, by regressing GDP per capita on environmental actions per capita, Lekakis and Kousis (2001) find that Greece, Spain and Portugal are either on the rising segment of the EKC or that the EKC does not exist. As for Bimonte (2009), it was found that countries that converge in economic growth also converge in their demand for environmental quality, but this does not diminish any direct relationship between income and environmental quality demand. As for more recent studies, the work of Kahn *et al.* (2022) finds that the EKC of China effectively shifts as a function of the demand for clean air in cities. In addition, Ohler (2015) explores unemployment as an alternative to income to explain preferences and discovers that lagged unemployment explains the demand for renewable energies better than income. In general, however, still not much contemporary research is focused on the factors that drive the demand for environmental quality as a dependent variable and many of the empirical studies estimate elasticities with respect to income alone (Dinda, 2004; Zilio, 2012; Figueroa & Pasten, 2015; Ben Jebli *et al*., 2022).

Data and methods

This study employs a countrywide panel of economic, social and environmental variables, during the period 2010 to 2020 and covering 16 European countries. Europe was chosen for the study as it is an area where countries of different economic, social and environmental levels can be found, but where we can isolate a common component of unobserved heterogeneity due to convergence (Casu & Girardone, 2010; Crespo Cuaresma *et al.*, 2008; Schönfelder & Wagner, 2019). Although all the countries of the European Union (EU) could not be chosen due to missing data, the study employs 57% of the countries in the EU to derive inferences. The countries are Belgium, Bulgaria, Czechia, Denmark, Germany, Estonia, Ireland, Greece, France, Italy, Lithuania, Hungary, the Netherlands, Poland, Portugal and

Spain. By choosing these countries, the paper covers a complete spectrum of income, from the 10,000 USD of GDP per capita of Bulgaria to the 67,000 USD of GDP per capita of Norway.

Data

The source of the data is Eurostat. The main independent variable is the Gross Domestic Product (GDP) Per Capita in real terms. The other independent variables are Consumption, Taxes, Social Benefits, R+D Investment, Comparative Price Levels, BERD, R+D Personnel, Employment, Pollution and Exposure to Air Pollution. The explanation for each random variable is presented in Table 1.

Most of the variables have been available since 2010, but the variable Pollution became available in 2011, and the variable Exposure to air pollution is only available until 2019. The observation of R+D Personnel for Greece in 2010 is not available either. Therefore, when the models include these variables, the panels are unbalanced. In all other cases, the panels are balanced.

These variables are selected because they control for the preferences side of the EKC (Dinda, 2004). R+D Investment, BERD and R+D Personnel are selected as the technological controls of the EKC, constituting the other main driver of the EKC (Figueroa & Pasten, 2013; Pasten & Figueroa, 2012). Environmental controls are finally added to determine the effect of living in a deteriorated environment and the exposure of the citizens to pollution on environmental quality demand.

As a dependent variable, we employ the random variable G, the Google trends index of "GreenHouse Gases" (hereafter GHG) for a country in a year as a proxy for environmental quality demand. This approach was proposed by Simionescu *et al*. (2021) for similar purposes.

In order to identify elasticities, natural logarithms are applied to the full set of variables. Since all the dependent and independent variables are in logs, all the models are in log-log scale and the β will directly account for elasticities.

Table 1 displays the essential descriptive statistics of the data. The number of observations is 176 for all variables but R+D Personnel (175), Exposure to Air Pollution (151), and Pollution (158). The variable G has a mean of 3.007, with a standard error of 0.725, a minimum value of 1.204 and a maximum value of 4.230, and 25th and 75th percentiles of 2.613 and 3.572, respectively. The distribution of *G* is skewed, as can be seen in Figure 6, which shows a histogram against a normal density plot of the most relevant variables. The variable *Y* has a mean value of 9.932, with a standard error of 0.595, a minimum value of 8.533 and a maximum value of 11.051. The 25th and 75th percentiles are 9.473 and 10.433. The distribution of *Y* is not centred due to choosing countries with very different GDP per capita. Nevertheless, most variables in the panel are characterized by small standard deviations-and centrality around the mean due to the logarithmic transformation, as Table 1 and Figure 6 show. The most centred variables are Social Benefits, Prices, Employment, Pollution, Exposure to Air Pollution, R+D Investment, Taxes, *G* and *Y*, which present standard deviations below one ($\sigma < 1$). On the contrary, Consumption, BERD, and R+D Personnel are the least centred, with values above one ($\sigma > 1$). With respect to the mean, the highest values are also obtained by Consumption, BERD and R+D Personnel, while the lower values are those of R+D Investment, Taxes, Social Benefits, *G*, Pollution and Exposure to Air Pollution.

From the perspective of correlations, Table 2 provides the Pearson correlation coefficient between the variables. The number of GHG searches (G) and the real income (Y) correlate positively as expected, with a value of 0.668. Other factors that correlate positively are the Business Enterprise R+D Expenditure (0.743), Consumption (0.615), R+D Investment (0.595), Prices (0.557) and Taxes (0.562).

Due to the (expected) high correlation between Y and Prices, with a value of 0.965, we drop the variable prices from the estimations due to collinearity. However, Taxes can act as a proxy, as taxes affect prices, and these co-move in the same direction. This is reflected by their positive correlation value of 0.871, the third largest correlation. We conclude that incorporating taxes into the model is sufficient.[3]

The second largest correlation is between Consumption and Business Enterprise R+D Expenditure (0.929). This reflects the impact that the research and development conducted by companies have on the products they offer, and on the interest of the consumer to buy them.

[3] We are implicitly considering a collinearity threshold of 0.9. This is motivated by the Variance Tolerance Factor (VTF). Indeed, in the applied statistics literature when the VTF is higher than 0.1, then collinearity is not considered a problem (Thompson *et al.*, 2017). A VTF > 0.1 equals a correlation lower than the 0.9.

Models

This paper adopts a hierarchical regression equations approach. By choosing this method, it is possible to analyze the evolution of the β coefficient corresponding to the elasticity of income-environmental quality demand ($\epsilon_{Y,G}$) with the inclusion of further co-variates relevant to the preferences side of the EKC. Additionally, it is possible to analyze the contribution of the inclusion of further variables to the variance of the environmental quality demand variable *G*, as well as to analyze the behavior of the correlated predictors (Lewis, 2007), such as Consumption and BERD.

The model is defined as follows

$$\mathrm{G_{it}} = \alpha + \mu_{\mathrm{i}} + \beta \mathrm{X_{it}} + \mathrm{U_{it}} \tag{1}$$

for individual components

$$G_{it} = \alpha + \lambda t + \beta X_{it} + U_{it} \tag{2}$$

for time components, and

$$G_{it} = \alpha + \mu_i + \lambda t + \beta X_{it} + U_{it} \tag{3}$$

for two-way components. Here i = 1,...,n stands for individual; t = 1,...,T stands for time; α is the constant term; X_{it} is the vector of regressors which includes Y_{it}; β is the vector of the coefficient parameters of the variables; U_{it} is the error term; μ_i is the individual effects and λ_t is the time effect. We include one variable in each regression equation, so $X_{it} = Y_{it}$ corresponds to the first equation; $X_{it} = \{Y_{it}, Consumption\}$ corresponds to the second, and so on.

Results

Model selection

To select the best set of models for the analysis, Table 3 presents a battery of Hausmann tests (Hausman, 1978). These tests are applied to models with the full set of independent variables.

The Hausmann test could not reject the null hypothesis of the following models: fixed within and random estimators with time effects, the between fixed estimator with individual effects, random effects estimator with two-way effects, and first differences estimator. The Hausmann test could not reject that the fixed within and random estimators with time effects were correctly specified in more contrasts than those of Table 3 with a value lying in the interval 0.90 > 1− p > 0.10. Nonetheless, the fixed within estimator with individual effects (Table 10) only has 16 observations, the random estimator with two-way effects (Table 11) has very low R^2 and adjusted R^2 values and no statistically significant parameters across the majority of the models, and the first differences estimator has very low R^2 and negative adjusted R^2 values across all the models, and no statistically significant parameters either. Thus, it can be concluded that the best performing models are the fixed within and random estimators with time effects, with which the rest of the analysis is performed.

Tables 4 and 5 show the estimates $\hat{\epsilon}_{Y,G}$ along with the estimates for other interesting elasticities, such as that of the technological dimension or the exposure to air pollution. The estimates are very similar in the case of both the fixed and the random effects.

It can be seen that all the estimates for the elasticity of income display the expected sign. All are positive, indicating the estimates are coherent, which is a logical result for the income-environmental quality relationship for GHG. Furthermore, the relationship displays a high explanatory power both in the fixed and the random scenarios (R^2 = 0.45 and adjusted R^2 of 0.42 and 0.44, respectively). Figure 5 shows that this relationship holds both within countries and across countries.

However, none of the estimates of $\epsilon_{Y,G}$ has a higher value than one, not even the model that only incorporates income as an independent variable. Therefore, every estimate of the elasticity of income-environmental quality demand is lower than one, or equivalently $\forall\hat{\epsilon}_{Y,G} : \hat{\epsilon}_{Y,G} < 1$. This result is consistent across fixed and random effects. In addition, the estimates for $\hat{\epsilon}_{Y,G}$ become substantially lower when including other relevant variables in the equations, indicating omitted variable biases in the uni-variate model. Figure 2 shows the evolution of the elasticity of income-environmental quality demand (y-axis) with the inclusion of every model that significantly varies the R^2 coefficient (x-axis). The variables that decrease $\hat{\epsilon}_{Y,G}$ when they enter the econometric specification are Consumption, R+D Investment of a country and the Business Enterprise R+D Expenditure. The latter two are referred to as General R+D and Private R+D. When Consumption enters the equation, $\hat{\epsilon}_{Y,G}$ diminishes from 0.82 and 0.81 to 0.57. When General R+D is included, $\hat{\epsilon}_{Y,G}$ decreases from 0.62 to 0.49. Finally, when Private R+D is incorporated, it drops from 0.49 to 0.25, far from an elasticity higher than the unity. Confidence intervals support these results, as Table 6 shows.

Our estimates contradict the assumption that the EKC comes from an elasticity of environmental quality demand higher than one.[4] Moreover, to obtain an elasticity of environmental quality demand higher than one, it is necessary to at least consider three variables, as Figure 4 shows. In addition to Income, BERD and Exposure to Air Pollution are needed to derive an EKC generated by preferences. Table 7 offers a battery of Wald tests that contrast whether $\hat{\epsilon}_{Y,G} > 1$ or otherwise in every model. When the null hypothesis is set as $2 \geq \hat{\epsilon}_{Y,G} \geq 1$, none of the tests allow the null hypothesis to be accepted as being true. However, when $\hat{\epsilon}_{Y,G} < 1$ is considered as the null hypothesis, there is always a value for which the test does not reject the null.

However, when centering the analysis around the set of variables that are consistently statistically significant, it is important to note that preferences are not exogenous to technological development, nor when measured as BERD or R+D Personnel. Indeed, as Table 4 shows, the estimates for both variables are consistently positive and statistically significant. Thus, besides the technological effect, there exists an elasticity of BERD-environmental quality demand that is meaningful both economically and statistically.

What is more, not only do the models show that more than one variable is needed to accompany income to have an elasticity above unity, and that the technological component defines the preferences for a cleaner environment, they also reveal that when measuring the different elasticities of the full set of co-variates with respect to environmental quality demand, some are higher than the elasticity of income. This is reflected in Figure 3, which shows the elasticities of each variable with respect to environmental quality demand. The variables which are consistently statistically significant in each model display an asterisk (*), i.e., BERD, R+D Personnel and Exposure to Air Pollution. BERD and Exposure to Air Pollution display a slightly higher elasticity than income in the full model (0.02 and 0.03 higher, respectively). For the case of BERD, this is also supported by confidence intervals

[4] In the Annex, Tables 10, 11 and 12 and Figure 5 are presented. They include alternative estimations that were discarded due to poor performance, as well as a visual representation of the linear fit of the model.

(see Table 6.) In the case of Exposure to Air Pollution, although the maximum value for its confidence interval is lower by 0.03 points, the interval is much more centered, with a minimum value of 0.10 rather than the minimum value of 0.03 for income.

Robustness analysis

In this subsection, the analysis is focused on the robustness of the estimates. Two alternative estimations are proposed to compare with the main results: (1) An estimation using the Instrumental Variables (IV) estimator (Table 8), and (2) An estimation using other relevant variables of the dataset as proxies of the main variables of interest (Table 9).

Employment is used as an instrument of income, while R+D Investment is used for BERD. Pollution is utilized in the case of Exposure to Air Pollution. The first instrument has a coefficient of 1.64, with $p < 0.000$, $F = 13.63$ and $R^2 = 0.08$. The second instrument has a coefficient of 0.29, with $p < 0.003$, $F = 9.04$ and $R^2 = 0.05$. The third instrument has a coefficient of 0.32 with $p < 0.000$, $F = 15.13$ and $R^2 = 0.10$. However, albeit a reasonably good instrument, the estimations of the Results section and Table 9 show that general pollution is not a good proxy for the exposure of the population to air pollution Exposure to Air Pollution. For this reason, Table 9 also offers the estimation employing the latter variable.

Tables 8 and 9 show that, whether employing an IV or a proxy estimation, the results of the analyses performed in this paper are consistent. When employing the IV estimator and obtaining $\hat{\beta}_{Y,G} > 1$, this effect disappears instantly when the effect of technology and the exposure of the population to air pollution are included in the equation. The same occurs with the proxy estimation. Furthermore, although employment has its own relevance in the structure of the EKC (Expósito *et al*., 2019; Gyamfi *et al*., 2020; Zhao & Luo, 2017), when employed as a proxy for economic activity we find that its effect on preferences quickly dissolves when adding technology and Exposure to Air Pollution to the equation, at least for the European Union (see Table 9).

Discussion

Although theoretical efforts have been made to derive the micro-foundations of the EKC, it has typically been derived from two main factors: preferences and technology (Ben Jebli *et al*., 2022; Pasten & Figueroa, 2012). Furthermore, there are few quantitative/empirical studies investigating which factors drive the demand for environmental quality, and most of them date back many years (Khanna & Plassmann, 2004; Lekakis & Kousis, 2001; McConnell, 1997), often focusing on regressions of income on pollutants, reinforcing the argument that environmental quality is a luxury good (Bo, 2011; Dkhili, 2022; Stern, 2017).

Contrary to these traditional assumptions, the results of a panel of sixteen European countries of many different income levels indicate that, as stated by Dinda (2004) and Pasten and Figueroa (2012), among others, income alone is not enough to drive the preferences for green energy, and that the elasticity of income-environmental quality demand is not above one, showing that environmental quality is not a luxury good. Furthermore, other variables are needed to obtain an elasticity of environmental quality demand above one. Factors such as technological development (Lantz & Feng, 2006; Lindmark, 2002) or the exposure of citizens to air pollution (Kahn *et al*., 2022) contribute substantially to the preferences for cleaner energy. The combination of three of those factors is needed to generate a turning point in the EKC, as Figure 4 shows. According to the results of this study, this curve is much more representative than, for example, Figure 1. Another important result found is that technology and preferences should not be explicitly divided in theoretical analyses without considering their interdependencies. This is due to the fact that technological development affects the preferences for green energy.

As stated by Dinda (2004), Figueroa and Pasten (2013), and Pasten and Figueroa (2012), theoretical models usually depend on two key parameters: the income-elasticity of marginal utility with respect to the environment (Figueroa & Pasten, 2013) or income-elasticity of environmental quality demand (Dinda, 2004) (preferences or demand side), and the elasticity of substitution between factors (Figueroa & Pasten, 2013) (technology or supply side). When preferences are the engine of the EKC, it is assumed that when income grows, people achieve better living standards and start to care about the environment. However, in the econometric models of this study, all the technological-side variables are statistically and economically significant to explain the preferences for cleaner energy (see Tables 4 and 5 and Figure 3), with Business Enterprise R+D Expenditure specially standing out. This variable may be crucial for the preferences for environmental quality.

Finally, this work documents that theoretical models aiming to explain the structure of the EKC must start to consider the exposure of the population to pollution and its relationship with the preferences for clean energy (Hasan *et al*., 2022; Dutta *et al*., 2023). Empirical models related to air pollution should also consider controlling for this variable (Kahn *et al*., 2022), as it has an important impact on the preferences for cleaner energy (as Figure 3 illustrates). In addition, given that the EKC varies according to pollutants (Lawell *et al*., 2018), another limitation is that further evidence may be needed to contrast and extend the results of the present study to pollutants that may be less perceptible to population than air pollution, such as chemical waste or water contamination (Expósito *et al*., 2019; Liu *et al*., 2021; Thompson, 2012). This may be motivated by the concerns of the European population after the COVID-19 pandemic, and the demand for reducing risks derived from a low environmental quality (Rume & Didar-Ul Islam, 2020).

Therefore, it is possible to observe the complexity of the demand for environmental quality and how the evolution of the EKC can be derived from a set of elasticities, as Figure 4 illustrates. These insights contribute directly to this analytical framework by proposing two elasticities that have been empirically proven to be relevant and significant to incorporate into new models.

Conclusions

The income-pollution relationship lies in the hypothesis that, when a population reaches a certain level of income, further growth decreases its pollution emissions rather than increasing them. One of the main assumptions that is made to explain this hypothesis is that the elasticity of income with respect to the preferences or demand for a cleaner environment is higher than one, which equates to assuming that the environment is a luxury good. This research aimed to provide evidence related to this assumption by calculating parameters for this elasticity for a panel of 16 European countries to investigate whether this elasticity is in fact the driver of the preferences for cleaner energy in Europe. Another objective was to analyze whether other factors are responsible for affecting preferences for cleaner energy and to what extent they do so.

The results of this research present robust evidence that the elasticity between income and environmental quality demand is not above the unity in Europe. Furthermore, other factors such as research and technological investment or the exposure of the population to air pollution possess a higher elasticity of environmental quality demand, and a combination of these three is necessary in order to obtain an elasticity above the unity. In fact, this implies that the division that the theoretical and empirical literature has made in the income-environment relationship, i.e.; a consumer's preference side and a technological development side, is not possible. The evidence presented in this study shows that research and technological development are not only drivers of the relationship, but that they also increase the demand for environmental quality. Moreover, the evidence shows that the perceived pollution levels in the air by the population play a crucial role in the preferences for cleaner energy.

Two policy actions can be derived from the evidence presented in this paper: (I) When investing public funds with the objective of improving consumer awareness to ultimately preserve the environment, discriminating between regions depending on the exposure of citizens to air pollution is important in order to compensate the effect that this variable has. Regions where citizens are more exposed have a higher demand of environmental quality, which may require focusing first on the regions that are less exposed to increase their demand for environmental quality and counterbalance. (II) This distinction can be applied at the national level, but may also be relevant at the local. Having publicly available, good quality data about the exposure of citizens to air pollution by provinces, as well as other relevant variables such as statistical measures of environmental quality demand, is crucial to all future public policies to be undertaken by the European Union, in order to address the SDG more adequately and to reduce risks associated to low environmental quality (e.g., new illness or pandemic situations).

One of the main limitations of this study is that it only employs macrodata. Estimating these elasticities at a micro level in different countries and comparing the results would be an interesting continuation of this work. Moreover, an entire line of research can be conducted in estimating elasticities with factors that are assumed to drive the EKC. These parameters were more present in the theoretical plane in the past. However, as this study shows, there are other components beyond classical theoretical assumptions that exert considerable influence on the income-pollution relationship, such as citizen exposure to air pollution. As the availability of data increases in the current era, estimating or approximating these elasticities is increasingly possible and necessary. New empirical evidence in this field can be an important counterpart to guide new theoretical developments.

In addition, as a future line of research derived from this paper, we plan to study any potential non-linear dynamics that may exist between its three main elasticities. Economic phenomena are full of non-linearities, and the factors governing the EKC hypothesis may not be an exemption. The elasticity of environmental quality demand with respect to income and other relevant variables may present non-linear interactions, complicating a simple single explanation of the EKC.

Finally, the elasticity of environmental quality demand may be explained through other variables, and other variables may affect the strength and direction of the relationship. Considering the moderating and mediating effects of an extensive set of exogenous variables to the model is an important extension that remains open to investigation by a future research article.

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Annex

Table 1. Descriptive statistics of the data

Statistic	N	Mean	St. Dev	Min	Pctl(25)	Pctl(75)	Max	Explanation
G	176	3.007	0.725	1.204	2.613	3.572	4.230	Environmental quality demand
Y	176	9.932	0.595	8.533	9.473	10.433	11.051	Gross Domestic Product (GDP) Per Capita in real terms
Consumption	176	11.967	1.405	8.953	11.228	12.909	14.405	Final consumption expenditure of households and non-profit institutions serving households in millions of Euros
Taxes	176	2.309	0.433	1.459	1.998	2.549	3.503	Current taxes on income, wealth, etc. as a proportion of the GDP of the country
Social Benefits	176	2.686	0.235	1.917	2.485	2.846	3.182	Social benefits, other than social transfers in kind, paid by the general government as a proportion of the GDP
Rd Investment	176	0.417	0.435	−0.635	0.172	0.779	1.247	Research and development expenditure as a proportion of the GDP
Prices	176	4.490	0.290	3.900	4.221	4.714	4.985	Ratio between Purchasing Power Parities (PPP) and the market ex-change rate for each country as comparative price levels
Berd	176	7.830	1.786	4.168	6.742	9.093	11.236	Business Enterprise Research and Development expenditure in millions of Euros
Rd Personnel	175	11.159	1.243	8.571	10.431	12.135	13.508	Full-time equivalent contracts
Employment	176	4.174	0.108	3.882	4.094	4.271	4.378	Total employment levels as a proportion to the population
Exposure to air pollution	151	2.643	0.400	1.569	2.393	2.931	3.721	Population weighted annual mean concentration of particulate matter at urban background stations in agglomerations in particulates of less than 2.5μm
Pollution	158	2.542	0.381	1.386	2.398	2.733	3.277	Pollution, grime and other environmental problems as the proportion of household which perceive this problem over the total number of house-holds

Table 2. Correlation matrix of the variables

	G	Y	Consumption	Taxes	Social Benefits	Rd Investment	Prices	Employment	Berd
G	1,000	0,693	0,603	0,631	0,128	0,584	0,647	0,340	0,721
Y	0,693	1,000	0,554	0,870	0,238	0,683	0,970	0,325	0,727
Consumption	0,603	0,554	1,000	0,658	0,576	0,428	0,506	-0,034	0,914
Taxes	0,631	0,870	0,658	1,000	0,582	0,687	0,882	0,090	0,769
Social Benefits	0,128	0,238	0,576	0,582	1,000	0,258	0,316	-0,460	0,445
Rd Investment	0,584	0,683	0,428	0,687	0,258	1,000	0,674	0,535	0,662
Prices	0,647	0,970	0,506	0,882	0,316	0,674	1,000	0,230	0,673
Employment	0,340	0,325	-0,034	0,090	-0,460	0,535	0,230	1,000	0,171
Berd	0,721	0,727	0,914	0,769	0,445	0,662	0,673	0,171	1,000

Table 3. Hausmann tests of model specification

	Time within	Time between	Time random	Individual within	Individual between	Individual random	Two ways	First differences
Time within	–	105.87	16.01	171.15	0.19***	171.15	4.43	32.16
		(0.00)	(0.04)	(0.00)	(0.99)	(0.00)	(0.82)	(0.00)
Time between	105.87	–	35.204	91.07	168.15	91.07	–	81.20
	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)		(0.00)
Time random	16.01	35.20	–	171.91	0.61***	171.91	2.698**	62.17
	(0.04)	(0.00)		(0.00)	(0.99)	(0.00)	(0.95)	(0.00)
Individual within	171.15	91.09	171.91	–	16.757	–	0.01***	42.95
	(0.00)	(0.00)	(0.00)		(0.03)		(0.99)	(0.00)
Individual between	0.19***	168.14	0.61***	16.76	–	16.76	–	5.37
	(0.99)	(0.00)	(0.99)	(0.03)		(0.03)		(0.72)
Individual random	171.15	91.07	171.91	–	16.76	–	0.01***	42.95
	(0.00)	(0.00)	(0.00)		(0.03)		(0.99)	(0.00)
Two ways	4.43	–	2.698**	0.01***	–	0.01***	–	1.95***
	(0.82)		(0.95)	(0.99)		(0.99)		(0.98)
First differences	32.164	81.20	62.17	42.95	5.33	42.95	1.95***	–
	(0.00)	(0.00)	(0.00)	(0.00)	(0.72)	(0.00)	(0.98)	

Note: ****p < 0.001; ***p < 0.01; **p < 0.05; *p < 0.1

Table 4. Panel data within fixed effects model with time components and HAC errors

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10
$\hat{\epsilon}_{(Y,G)}$	0.82****	0.57****	0.60****	0.62****	0.49***	0.25*	0.32***	0.27**	0.29*	0.27*
	(0.07)	(0.09)	(0.11)	(0.13)	(0.15)	(0.14)	(0.11)	(0.11)	(0.15)	(0.15)
Consumption		0.18****	0.18****	0.17****	0.18****	−0.52***	−0.25**	−0.21*	−0.12	−0.09
	–	(0.03)	(0.03)	(0.03)	(0.04)	(0.19)	(0.12)	(0.12)	(0.16)	(0.16)
Taxes			−0.04	−0.07	−0.20	−0.02	−0.19	−0.02	−0.04	0.08
	–	–	(0.16)	(0.13)	(0.16)	(0.14)	(0.14)	(0.16)	(0.17)	(0.20)
Social Benefits				−0.30	−0.21	−0.30	−0.85****	−0.70****	−0.61**	−0.54**
	–	–	–	(0.23)	(0.22)	(0.19)	(0.17)	(0.18)	(0.24)	(0.23)
Rd Investment					0.40**	−0.60**	−0.23	−0.45**	−0.26	−0.25
	–	–	–	–	(0.18)	(0.26)	(0.20)	(0.23)	(0.31)	(0.31)
Berd						0.73****	0.44****	0.43****	0.33**	0.29*
	–	–	–	–	–	(0.19)	(0.12)	(0.12)	(0.16)	(0.16)
Rd Personnel							0.20****	0.16****	0.14****	0.13***
	–	–	–	–	–	–	(0.03)	(0.04)	(0.04)	(0.04)
Employment								1.09**	1.17	1.25
	–	–	–	–	–	–	–	(0.52)	(0.76)	(0.77)
Exposure to air pollution									0.27**	0.30***
	–	–	–	–	–	–	–	–	(0.11)	(0.11)
Pollution										−0.14
	–	–	–	–	–	–	–	–	–	(0.13)

Note: ****p < 0.001; ***p < 0.01; **p < 0.05; *p < 0.1

Table 5. Panel data random effects model with time components and HAC errors

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
(Intercept)	−5.07****	−4.80****	−5.01****	−4.35****	−3.15***	1.52	−0.46	−2.11
	(0.77)	(0.69)	(0.89)	(0.83)	(1.15)	(2.10)	(1.24)	(2.51)
$\hat{\epsilon}_{(Y,G)}$	0.81***	0.57****	0.61****	0.62****	0.49****	0.27*	0.33***	0.31***
	(0.07)	(0.09)	(0.12)	(0.13)	(0.14)	(0.14)	(0.11)	(0.12)
Consumption		0.18****	0.18****	0.17****	0.18****	−0.45**	−0.19	−0.16
	−	(0.03)	(0.03)	(0.03)	(0.04)	(0.19)	(0.12)	(0.12)
Taxes			−0.06	−0.08	−0.22	−0.06	−0.21	−0.16
	−	−	(0.12)	(0.16)	(0.16)	(0.14)	(0.14)	(0.16)
Social Benefits				−0.26	−0.17	−0.24	−0.77****	−0.69****
	−	−	−	(0.16)	(0.21)	(0.19)	(0.17)	(0.18)
Rd Investment					0.40**	−0.50*	−0.14	−0.18
	−	−	−	−	(0.18)	(0.26)	(0.20)	(0.22)
Berd						0.65***	0.38***	0.36***
	−	−	−	−	−	(0.16)	(0.12)	(0.12)
Rd Personnel							0.19****	0.18****
	−	−	−	−	−	−	(0.03)	(0.04)
Employment								0.35
	−	−	−	−	−	−	−	(0.49)

Note: ****p < 0.001; ***p < 0.01; **p < 0.05; *p < 0.1

Table 6. Confidence intervals at a 90 % level for the within fixed effects estimator

	Model 1	Model 2	Model 3	Model 4	Model 5	Model ~~6~~	Model 7	Model 8	Model 9	Model 10
β_{Y}	0.82∗	0.57∗	0.60∗	0.62∗	0.49∗	0.25∗	0.32∗	0.27∗	0.29∗	0.27∗
	[0.68;0.95]	[0.42;0.73]	[0.36;0.84]	[0.38;0.86]	[0.23;0.74]	[0.01;0.49]	[0.10;0.54]	[0.05;0.49]	[0.05;0.52]	[0.03;0.52]
β_{C}		0.18∗	0.18∗	0.17∗	0.18∗	−0.52∗	−0.25∗	−0.21	−0.12	−0.09
	–	[0.11;0.24]	[0.11;0.24]	[0.11;0.24]	[0.11;0.24]	[−0.76;−0.28]	[−0.48;−0.01]	[−0.45;0.02]	[−0.37;0.13]	[−0.34;0.16]
β_{T}			−0.04	−0.07	−0.20	−0.02	−0.19	−0.02	−0.04	0.08
	–	–	[−0.36;0.28]	[−0.39;0.25]	[−0.52;0.12]	[−0.32;0.28]	[−0.46;0.09]	[−0.33;0.30]	[−0.37;0.30]	[−0.30;0.45]
β_{SB}				−0.30	−0.21	−0.30∗	−0.85∗	−0.70∗	−0.61∗	−0.54∗
	–	–	–	[−0.63;0.03]	[−0.54;0.11]	[−0.60;−0.01]	[−1.17;−0.52]	[−1.05;−0.36]	[−0.98;−0.24]	[−0.94;−0.15]
β_{RD}					0.40∗	−0.60∗	−0.23	−0.45∗	−0.26	−0.25
	–	–	–	–	[0.13;0.66]	[−1.02;−0.19]	[−0.62;0.17]	[−0.90;−0.01]	[−0.76;0.23]	[−0.76;0.26]
β_{BERD}						0.73∗	0.44∗	0.43∗	0.33∗	0.29∗
	–	–	–	–	–	[0.48;0.97]	[0.20;0.68]	[0.20;0.67]	[0.07;0.58]	[0.03;0.55]
$\beta_{RD.P}$							0.20∗	0.16∗	0.14∗	0.13∗
	–	–	–	–	–	–	[0.13;0.26]	[0.09;0.24]	[0.06;0.22]	[0.05;0.21]
β_{EM}								1.09∗	1.17∗	1.25∗
	–	–	–	–	–	–	–	[0.08;2.10]	[0.09;2.25]	[0.16;2.34]
β_{EAP}									0.27∗	0.30∗
	–	–	–	–	–	–	–	–	[0.09;0.45]	[0.10;0.49]
~~β_{P}~~										−0.14
	–	–	–	–	–	–	–	–	–	[−0.38;0.09]
R^2	0.45	0.53	0.53	0.54	0.57	0.64	0.71	0.72	0.73	0.74
Adj. R^2	0.42	0.50	0.50	0.50	0.53	0.61	0.68	0.68	0.70	0.70
Num.obs.	176	176	176	176	176	176	175	175	151	148

Note: ∗ equals statistical significant.

Table 7. Wald tests for $\hat{\epsilon}_{Y,G} > 1$

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10
Fixed effects										
$H0$: $\hat{\beta}_{Y,G} = \theta$	0.89	0.89	0.65	0.92	0.128	0.00	0.43	0.31	0.09	0.04
	(0.35)	(0.35)	(0.42)	(0.33)	(0.91)	(0.98)	(0.51)	(0.86)	(0.77)	(0.85)
$H0 : \hat{\beta}_{Y,G} = 1$	6.92**	28.98**	10.52***	9.65***	16.09***	36.76***	36.22***	40.99***	36.08***	34.62***
	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$H0 : \hat{\beta}_{Y,G} = 1.25$	38.51***	73.03***	27.76***	26.42***	35.51***	65.49***	67.94***	73.88***	65.74***	62.57***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$H0 : \hat{\beta}_{Y,G} = 1.5$	95.65***	137.08***	53.21***	51.48***	65.52***	102.45***	109.56***	116.38***	104.23***	98.72***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$H0 : \hat{\beta}_{Y,G} = 1.75$	178.35***	221.14***	86.87***	84.76***	97.15***	147.65***	161.08***	168.5***	151.55***	143.09***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$H0 : \hat{\beta}_{Y,G} = 2$	286.61***	325.19***	128.74***	126.33***	139.34***	201.09***	222.48***	230.24***	207.7***	195.66***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Degrees of freedom	1	1	1	1	1	1	1	1	1	1
Res. Degrees of freedom	164	163	162	161	160	159	157	156	132	128
Random effects	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**	**Model 9**	**Model 10**
$H0 : \hat{\beta}_{Y,G} = \theta$	0.84	0.84	0.75	0.95	0.01	0.04	0.47	0.29	0.09	0.04
	(0.36)	(0.36)	(0.38)	(0.33)	(0.92)	(0.84)	(0.49)	(0.59)	(0.77)	(0.85)
$H0 : \hat{\beta}_{Y,G} = 1$	7.41**	30.20***	10.54***	9.90***	16.56***	34.45***	34.66***	33.93***	36.08***	34.62***
	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$H0 : \hat{\beta}_{Y,G} = 1.25$	40.43***	75.69***	28.12***	27.09***	36.60***	62.28***	65.25***	63.12***	65.74***	62.57***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$H0 : \hat{\beta}_{Y,G} = 1.5$	99.94***	141.72***	54.14***	52.77***	64.50***	98.27***	105.44***	101.30***	104.23***	98.72***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$H0 : \hat{\beta}_{Y,G} = 1.75$	185.9***	228.29***	88.62***	86.93***	100.2***5	142.45***	155.23***	148.47***	151.55***	143.09***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$H0 : \hat{\beta}_{Y,G} = 2$	298.34***	335.40***	131.54***	129.57***	143.85***	194.81***	214.61***	204.63***	207.7***	195.66***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Degrees of freedom	1	1	1	1	1	1	1	1	1	1
Res. Degrees of freedom	164	163	162	161	160	159	157	156	132	128

Source: own calculations. θ = 0.75 in Model 1, θ = 0.50 in Models from two to five, and θ = 0.25 in Models from 6 to 10. ****p < 0.001; ***p < 0.01; **p < 0.05; *p < 0.1

Table 8. Robustness check of the results by using IV estimation

	Model 1 (f.e.)	Model 2 (f.e.)	Model 3 (f.e.)	Model 1 (r.e.)	Model 2 (r.e.)	Model 3 (r.e.)
$\hat{\beta}_{(Y,G)}$	1.55***	1.38	0.53	1.42***	0.82	0.47
	(0.33)	(1.02)	(0.33)	(0.28)	(1.33)	(0.28)
Berd		0.11	0.43**		0.32	0.39**
	–	(0.49)	(0.15)	–	(0.61)	(0.13)
Exposure to air pollution			−0.20			0.10
	–	–	(0.40)	–	–	(0.30)
Intercept	–	–	–	−11.12***	−7.68	−4.96*
	–	–	–	(2.79)	(8.55)	(2.10)
R2	0.45	0.52	0.59	0.45	0.58	0.61
Adj. R2	0.42	0.48	0.56	0.44	0.57	0.60
Num. obs.	176	176	148	176	176	148
s idios				0.71	0.70	0.68
s time				0.00	0.00	0.18

Note: ****p < 0.001; ***p < 0.01; **p < 0.05; *p < 0.1

Table 9. Robustness check of the results by using proxy variables

	Model 1 (f.e.)	Model 2 (f.e.)	Model 3 (f.e.)	Model 4 (f.e.)	Model 1 (r.e.)	Model 2 (r.e.)	Model 3 (r.e.)	Model 4 (r.e.)
Employment	2.55***	0.22	0.04	0.35	2.31***	0.15	−0.10	0.51
	(0.52)	(0.54)	(0.57)	(0.55)	(0.48)	(0.49)	(0.52)	(0.51)
Rd		0.98***	1.02***	1.02***		0.97***	1.00***	1.00***
	–	(0.13)	(0.13)	(0.13)	–	(0.12)	(0.13)	(0.12)
Pollution			−0.03				−0.03	
	–	–	(0.12)	–	–	–	(0.12)	–
Exposure to air pollution				0.59***				0.58***
	–	–	–	(0.12)	–	–	–	(0.11)
Intercept					−6.64***	1.96	3.07	−1.06
	–	–	–	–	(2.00)	(2.03)	(2.19)	(2.16)
R2	0.13	0.36	0.39	0.45	0.12	0.35	0.37	0.45
Adj. R2	0.07	0.32	0.33	0.40	0.11	0.35	0.36	0.43
Num. obs.	176	176	158	151	176	176	158	151
s idios					0.69	0.59	0.58	0.54
					0.00	0.00	0.00	0.00

Note: ****p < 0.001; ***p < 0.01; **p < 0.05; *p < 0.1

Table 10. Panel data within fixed effects model with individual components and HAC errors

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10
Intercept	5.19*	-4.91	-5.13	-4.57	-2.92	2.84	1.05	-7.94	-9.93	-15.84
	(2.23)	(2.12)	(3.13)	(3.66)	(3.99)	(5.00)	(5.00)	(14.24)	(15.19)	(18.10)
$\hat{\epsilon}_{(Y,G)}$	0.83**	0.58*	0.62	0.63	0.43	0.19	0.26	0.19	0.19	0.15
	(0.22)	(0.26)	(0.44)	(0.46)	(0.50)	(0.48)	(0.46)	(0.49)	(0.50)	(0.53)
Consumption		0.18	0.18****	0.17****	0.18****	−0.61***	−0.34**	−0.33*	−0.22	−0.18
	–	(0.11)	(0.11)	(0.12)	(0.12)	(0.48)	(0.50)	(0.52)	(0.52)	(0.56)
Taxes			−0.06	−0.07	−0.25	−0.04	−0.22	0.15	0.11	0.77
	–	–	(0.59)	(0.61)	(0.64)	(0.60)	(0.58)	(0.81)	(0.83)	(1.22)
Social Benefits				0.30	−0.21	−0.30	−0.85****	−0.70****	−0.61**	−0.54**
	–	–	–	(0.63)	(0.65)	(0.60)	(0.58)	(0.81)	(0.83)	(1.22)
Rd Investment					0.40	−0.60	−0.25	−0.8	−0.57	−1.06
	–	–	–	–	(0.61)	(0.68)	(0.64)	(1.24)	(1.33)	(1.58)
Berd						0.82	0.54	0.57	0.46	0.41
	–	–	–	–	–	(0.48)	(0.51)	(0.53)	(0.57)	(0.52)
Rd Personnel							0.20	0.18	0.21	0.22
	–	–	–	–	–	–	(0.14)	(0.18)	(0.20)	(0.23)
Employment								2.03	2.04	3.49
	–	–	–	–	–	–	–	(3)	(3.25)	(3.87)
Exposure to air pollution									0.28	0.33
	–	–	–	–	–	–	–	–	(0.39)	(0.47)
Pollution										−0.17
	–	–	–	–	–	–	–	–	–	(0.68)
R^2	0.49	0.58	0.58	0.58	0.62	0.71	0.77	0.78	0.80	0.82
Adj. R^2	0.46	0.46	0.51	0.47	0.43	0.43	0.52	0.57	0.54	0.51
Num. Obs.	16	16	16	16	16	16	16	16	16	16

Note: ****p < 0.001; ***p < 0.01; **p < 0.05; *p < 0.1

Table 11. Panel data random effects model with two ways components and HAC errors

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
(Intercept)	−1.34	-1.80	-1.80	0.35	0.48	0.41	-0.55	0.07
	(1.62)	(1.57)	(1.62)	(1.66)	(2.55)	(2.64)	(13.51)	(13.55)
$\hat{\epsilon}_{(Y,G)}$	0.44∗∗	0.21	0.22	0.23	0.22	0.24	0.21	0.30
	(0.16)	(0.19)	(0.20)	(0.21)	(0.22)	(0.21)	(0.20)	(0.24)
Consumption		0.23∗	0.24∗	0.22	0.21	0.23	0.24	0.22
	–	(0.10)	(0.11)	(0.16)	(0.18)	(0.20)	(0.21)	(0.23)
Taxes			−0.13	−0.16	−0.18	−0.23	−0.24	−0.32
	–	–	(0.12)	(0.16)	(0.20)	(0.24)	(0.22)	(0.29)
Social Benefits				−0.28	−0.19	−0.26	−0.78	−0.89
	–	–	–	(0.26)	(0.21)	(0.24)	(0.68)	(1.22)
Rd Investment					-0.19	−0.20	−0.23	−0.33
	–	–	–	–	(0.18)	(0.26)	(0.28)	(0.40)
Berd						0.05	0.01	0.06
	–	–	–	–	–	(0.16)	(0.18)	(0.23)
Rd Personnel							0.21	0.22
	–	–	–	–	–	–	(0.49)	(0.49)
Employment								-0.66
	–	–	–	–	–	–	–	(2.28)
s. idios	0.20	0.20	0.18	0.17	0.23	0.22	0.19	0.21
s. id	0.52	0.49	0.51	0.48	0.53	0.54	0.47	0.48
s. time	0.10	0.10	0.09	0.04	0.05	0.02	0.11	0.00
R^2	0.04	0.07	0.14	0.15	0.13	0.45	0.50	0.52
Adj. R^2	0.03	0.05	0.12	0.13	0.10	0.11	0.43	0.47
Num. Obs.	176	176	176	176	176	176	175	175

Note: ∗∗∗∗p < 0.001; ∗∗∗p < 0.01; ∗∗p < 0.05; ∗p < 0.1

Table 12. Panel data first differences model with HAC errors

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
(Intercept)	0.00	0.00	0.00	0.00	-0.01	0.00	-0.01	0.00
	(0.02)	(0.03)	(0.02)	(0.04)	(0.03)	(0.02)	(0.04)	(0.02)
$\hat{\epsilon}_{(Y,G)}$	0.27	0.30	0.28	0.24	0.43	0.75	0.71	0.67
	(0.41)	(0.53)	(0.58)	(0.61)	(0.66)	(0.70)	(0.72)	(0.75)
Consumption		0.02	0.04	-0.06	-0.13	-0.13	-0.00	-0.04
	–	(0.58)	(0.59)	(0.63)	(0.63)	(0.63)	(0.64)	(0.67)
Taxes			−0.05	−0.05	−0.00	−0.01	0.00	0.00
	–	–	(0.26)	(0.26)	(0.26)	(0.26)	(0.26)	(0.26)
Social Benefits				−0.26	−0.21	−0.23	−0.84	−0.86
	–	–	–	(0.31)	(0.31)	(0.31)	(0.31)	(0.31)
Rd Investment					0.29	0.56	0.70	0.70
	–	–	–	–	(0.20)	(0.35)	(0.35)	(0.36)
Berd						-0.23	-0.28	-0.28
	–	–	–	–	–	(0.24)	(0.24)	(0.24)

Table 12. Continued

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Rd Personnel							0.23	0.28
	–	–	–	–	–	–	(0.28)	(0.28)
Employment								0.19
	–	–	–	–	–	–	–	(1.09)
R^2	0.00	0.00	0.00	0.00	0.02	0.02	0.04	0.04
Adj. R^2	0.00	-0.01	-0.02	-0.01	-0.01	-0.02	-0.01	-0.02
Num. Obs.	160	160	160	160	160	160	159	159

Note: ∗∗∗∗p < 0.001; ∗∗∗p < 0.01; ∗∗p < 0.05; ∗p < 0.1

Table 13. Robustness check of the results by using polinomial terms.

	Model 1 (f.e.)	Model 2 (f.e.)	Model 3 (f.e.)	Model 1 (r.e.)	Model 2 (r.e.)	Model 3 (r.e.)
$\hat{\epsilon}_{(Y,G)}$	0.82***	0.82***	0.82***	0.81***	0.81***	0.81***
	(0.06)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)
Y^2		0.64	0.64		0.65	0.65
	–	(0.55)	(0.55)	–	(0.54)	(0.54)
Y^3			0.00			-0.03
	–	–	(0.55)	–	–	(0.54)
Intercept	–	–	–	−5.07***	−5.07***	−5.07***
				(0.68)	(0.68)	(0.68)
R2	0.45	0.46	0.46	0.45	0.45	0.45
Adj. R2	0.42	0.42	0.41	0.44	0.44	0.44
Num. obs.	176	176	158	176	176	176
s idios				0.30	0.30	0.30
				(0.55)	(0.55)	(0.55)

Note: ∗∗∗∗p < 0.001; ∗∗∗p < 0.01; ∗∗p < 0.05; ∗p < 0.1

Figure 1. Graphical representation of the EKC driven by preferences as in Dinda 2004

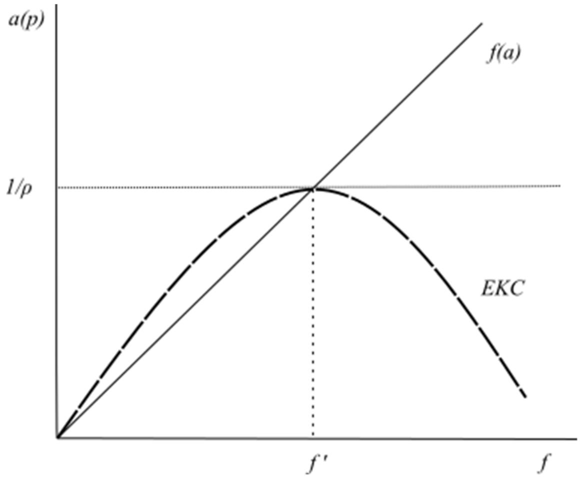

Figure 2. Evolution of the income elasticity of environmental quality demand ($\hat{\epsilon}_Y$) with the inclusion of further variables

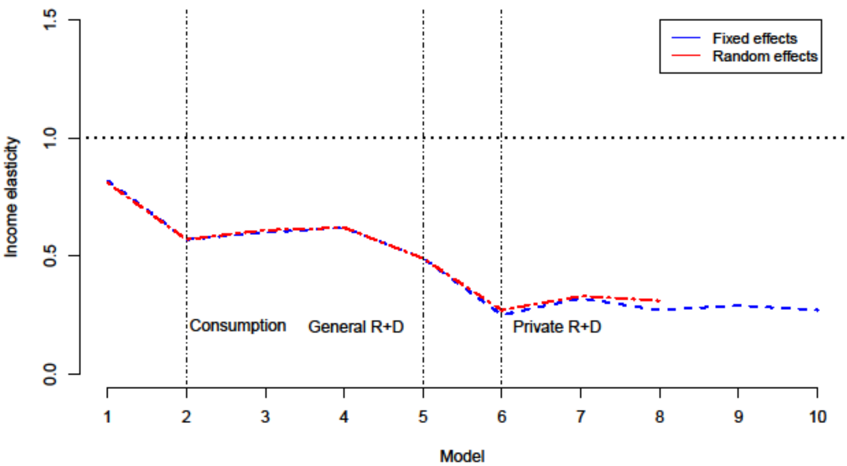

Figure 3. Elasticities of environmental quality demand for the full set of variables

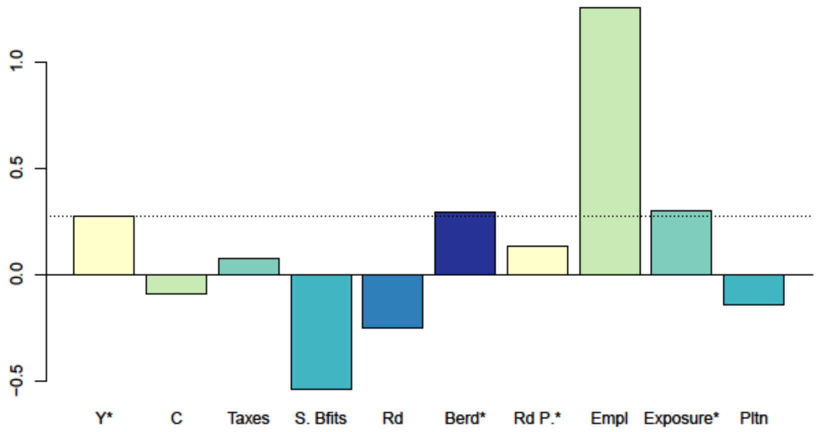

Figure 4. EKC driven by a combined elasticity of environmental quality demand

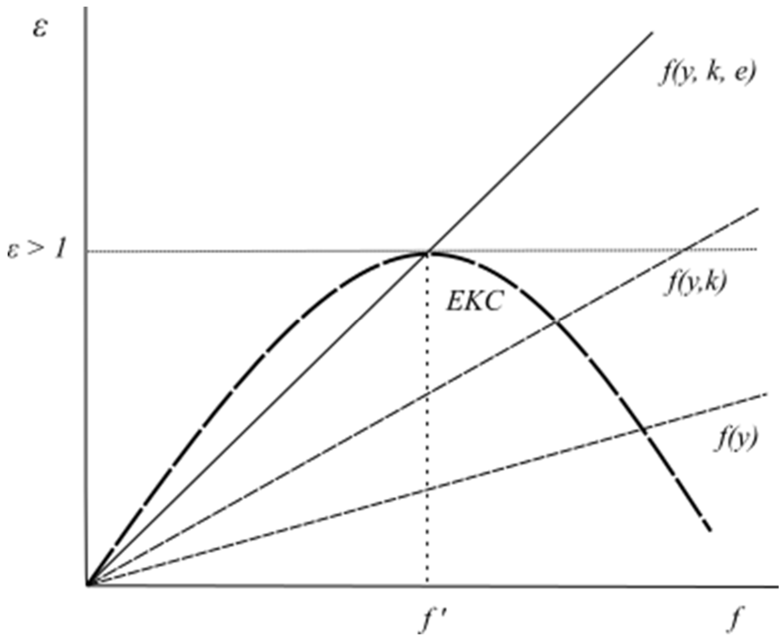

Figure 5. Pooling and within linear trends of the within fixed time effects panel data model with income as the only explanatory variable

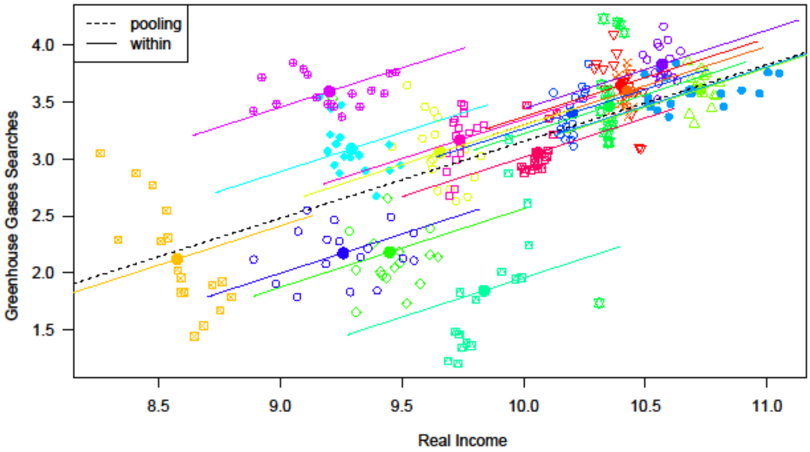

Figure 6. Histogram against normal density plot of the main variables