

**IS THERE AN ENVIRONMENTAL KUZNETS CURVE FOR WATER USE? A PANEL SMOOTH
TRANSITION REGRESSION APPROACH**

Rosa Duarte^{a)}, Vicente Pinilla^{b)} and Ana Serrano^{c)*}

^{a)}Department of Economic Analysis, Faculty of Economics and Business Studies, Universidad de Zaragoza, Gran Vía 2, 50005 Zaragoza, Spain, rduarte@unizar.es

^{b)} Department of Applied Economics and Economic History, Faculty of Economics and Business Studies, Universidad de Zaragoza, Gran Vía 2, 50005 Zaragoza, Spain, vpinilla@unizar.es

^{c)}Department of Economic Analysis, Faculty of Economics and Business Studies, Universidad de Zaragoza, Gran Vía 2, 50005 Zaragoza, Spain, asergon@unizar.es. Tel: +34 976 761786 ext. 4621; fax: +34 976 761996

Abstract: This paper presents an analysis of the relationship between per capita water use and per capita income for 65 countries over the period 1962-2008 within the framework of the so-called environmental Kuznets curve (EKC). Consistent with the existing literature, a polynomial fixed effects model is firstly presented. Then, a logistic Panel Smooth Transition Regression (PSTR) is estimated, capturing individual heterogeneity and time variability of income elasticity. This empirical study yields several important findings. The nexus between water withdrawal per person and per capita GDP is non-linear, showing a peculiar U-inverted with a marked downward limb that dominates the nexus regardless the estimation method chosen. On the whole, water use income elasticity clearly decreases throughout the period; nevertheless it exhibits a great variability over the sample, reflecting the divergent patterns of water use depending on the level of income of each country and period.

Keywords: Water use, Panel Smooth Transition Regression model, Environmental Kuznets Curve, nonlinearity, per capita income.

* Corresponding author. Department of Economic Analysis. Faculty of Economics. Gran Vía 2, 50005 Zaragoza (Spain) Tel: 34976762213 Fax:34976761996 e-mail: asergon@unizar.es

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1. Introduction

According to WHO/UNICEF (2000), currently more than 2 billion people are concerned by water shortages in over forty countries. Water is one of the most precious resources in the world, which plays a relevant role in economic development. Water is essential for human and ecosystem needs and the availability, use and management of freshwater is vital not only for human welfare, but also for environmental conservation. The limited supply of freshwater, coupled with an exponential growth in demand, seriously threatens the integrity of the natural world as well as the well-being of humanity. Thus, correctly understanding the nexus between water use and per capita income using global data appears to be interesting to identify current trends and foresee future ones; especially in view of the perspectives of international institutions like FAO that states: “by 2025, 1,800 million people will be living in countries or regions with absolute water scarcity, and two-thirds of the world population could be under stress conditions”.

The relationship between economic growth and the use of natural resources or emissions has received great attention from the early seventies and the debate continues nowadays. To date, many studies have analyzed environmental pressures from an economic perspective; pointing at population, economic development, urbanization or industrialization as some of the driving forces for natural resources depletion (Nakicenovic et al., 2000; Kander and Lindmark, 2004; WWAP, 2009).

In this general context, the hypothesis of an U-inverted relationship between environmental pressures and economic growth has been put in the foreground. Based on a similar association between the level of inequality and per capita income (Kuznets,

1955), this relationship was named as the Environmental Kuznets Curve (EKC hereafter). The baseline idea is very simple: At a first stage the greater income is, the higher pressure on natural resources. Then, after reaching an income threshold the trend reverses and the pressure on natural resources tends to decrease. Since the seminal papers of Shafik and Bandyopadhyay (1992), Panayotou, (1993) Selden and Song (1994) and Grossman and Krueger (1995) a lot of research on this topic has been carried out. In all of them the cross-country evidence pointed at an inverted-U curve between pollution indicators and income per capita; nevertheless the turning points are rather divergent. The EKC approach has not already drawn a consistent conclusion and the discussion on its shortcomings still continues these days. On the one hand, the debate focuses on the explanations of the decreasing component (Stern et al., 1996; Ekins, 1997; Roca et al., 2001; Gales et al., 2007; Fouquau et al., 2009). On the other hand, many of the drawbacks refer to econometric issues such as heterogeneity (Mazzanti and Mussolessi, 2010; Vollebergh et al. , 2009), functional form or spatial dependence (Stern, 2004; Aslanidis, 2009).

On the whole, most research on the EKC deals with pollutant emissions and energy. However, there are few studies examining the link between water resources and per capita income. The lack of consistent data or the relative abundance of water in developed countries, among other causes, left the water resources evaluation from a similar perspective out. The few works on this topic, (Cole, 2004; Katz, 2008) study the cross-country or panel-data evidence using polynomial models and seem to be consistent with the existence of an EKC for water use. These models present, however, two major drawbacks. Firstly, they use limited global datasets with few observations; what could reduce the precision for the estimates that reflect the variability not only

among individuals, but also among temporal periods. Secondly, the use of polynomial panel data models assuming that elasticity depends indirectly on income, across the N countries and the T periods of the sample, seems to be quite restrictive. In our opinion, an econometric method that allows the parameters to change smoothly appears to be more accurate to capture the heterogeneous behavior of countries whose actions are not identical and follow a slow pace, as can be expected in the case of water uses.

Therefore, the main purpose of this article is to empirically study the nexus between per capita income and water withdrawal. From a theoretical point of view, the increase in water use during the first stages of economic development would be due to the rise of food of high income elasticity, that in general are more water intensive, industrialization and water requirements of their activities as well as urbanization processes and the development of running water systems. Since agriculture has been, and still is, the main water consumer, particularly important is the expansion of irrigation that took place in many places to enable the increase in production. The possible fall in per capita water use would be related to technological developments, that particularly in agriculture have generated more efficient irrigation systems, to structural change owing to the share increase of activities with low water intensity, such as industry or services, and the setup of specific policies that look for an increase in efficiency in view of scarcity problems (Duarte et al., 2011). It seems reasonable to think that countries in process of development have taken advantage of technological advances that save water in the last decades and thus could require less water per person than pioneering countries in industrialization and modern economic growth (Dasgupta et al., 2002). Obviously a country water use do not only depends on income but also on their climatic conditions and water management. To take into account these other factors we must add two

control variables. The first one, precipitations, is used as a proxy for water availability. The second one, political freedom, tries to measure the quality of institutions.

For our empirical strategy we will use the traditional the traditional panel data models together with the Panel Smooth Transition Regression (PSTR, hereafter) approach. PSTR models, opposite to polynomial models, have the advantages of providing the water-income nexus with more flexibility, capturing cross-country heterogeneity and time variability. To this end, we use a logistic PSTR model with per capita income as a threshold variable, which allows the “income-water withdrawal” link to be influenced by a transition variable, that is, per capita income. Besides, PSTR models are quite innovative and some empirical applications have been recently published (Chang et al., 2011; Lee and Chiu, 2011; Chiu, 2012).

This methodology is applied to a water use balanced panel of 65 countries over the years 1960-2008. In our view, the contribution of this article is twofold. Firstly as far as we know, this kind of model is used to explore the “water use-income” nexus for the first time, contributing to literature on the relationship of the use of water resources and GDP per capita. Moreover, the use of a larger dataset than in the few previous works could provide a better overview of the interactions between these two variables, being a step forward in the analysis of the relationships between economic growth and the use of water resources. Secondly, unlike previous studies on the same topic, the PSTR provides a quantification of the “water use-income” relationship depending on the country and temporal period, since elasticities can be obtained as a weighted average of the estimates. That way, it is possible to examine the different water use patterns according to the level of development of each cross-section; adopting a temporal

perspective which is really important to understand the historical influence of income on water use.

Although water use is found to increase for the lowest values of per capita income, our findings seem to globally point at a negative association between per capita income and per capita water withdrawal, regardless the model used. Our results say that there exists a particular EKC with a decreasing limb that dominates the link between these two variables from 1960 to nowadays; nonetheless, these data should be put in perspective, trying to link them with the little information available for the first half of the twentieth century. A polynomial and PSTR models are estimated; nevertheless the second ones are preferred by linearity tests, since they captures heterogeneity and non linearities in the dataset. The estimated elasticities show the great variability of the data; finding different country individual patterns. The least developed countries in the sample show positive elasticities that tend to increase until 1995, when this trend reverses. Emerging countries, like China, display decreasing elasticities, from positive to negative values. Finally the richest countries in the dataset exhibit negative elasticities that seem to decrease throughout the period, although at a slower pace during the last decades. Nevertheless, it will be necessary to examine these results in a broader temporal framework. Eventually, we add two control variables to the polynomial and the PSTR models. The first one, precipitations, is used as a proxy for water availability. The second one, political freedom, tries to measure the quality of institutions. Both of them appear as significant to explain water use per person and have the expected sign.

The remainder of the article proceeds as follows. The next section introduces the methodology describing the PSTR model, the specification and the estimation

procedures. Section three describes the data and presents the empirical results. In section four a discussion of the results is presented. Finally section five concludes.

1. Methodology

2.1. The PSTR model

Traditional literature on the EKC commonly uses polynomial models, which basically consist of estimating the well-known fixed effects model by ordinary least squares (Cole, 2004; Katz, 2008). Apart from the polynomial estimation; in this paper we adopt a PSTR model. Extension of panel threshold regressions (Hansen, 1999), the PSTR was first applied by González et al. (2005) to examine the effect of capital market

imperfections on investment. This methodology has been commonly used in finance (Chang et al., 2011) and recently, in environmental economics (Aslanidis and Xepapadeas, 2006; Lee and Chiu, 2011; Chiu, 2012). However water issues have not been studied from this perspective. After estimating a PSTR model for the relationship of income with energy intensity and electricity consumption, respectively, Destais et al. (2007) and Bessec and Fouquau (2008) summarize the three main advantages of this type of models. Firstly, they capture the heterogeneity in the dataset, since it allows for a smooth transition between the extreme regimes. In the second place, the threshold value is not given a priori, but it is calculated in the model. Finally, they offer a parametric method to examine the individual heterogeneity and time variability of income elasticity. In addition, as income is also added as explanatory variable, its

impact on water use is easy to measure. Therefore, capturing nonlinearities and regime switching, makes the PSTR a good tool for the study of the “per capita income-water use relationship”.

The simplest model with individual-fixed effects is defined as follows:

$$W_{it} = \mu_i + \beta_1 Y_{it} + \beta_2 Y_{it} g(Y_{it}; \gamma, c) + \varepsilon_{it} \quad (1)$$

$$i = 1, \dots, N \quad t = 1, \dots, T$$

where W_{it} is the logarithm of per capita water withdrawal in country i in year t , Y_{it} is the logarithm of per capita income in country i in year t , μ_i are the country specific effects and ε_{it} is an error term. The transition function $g(Y_{it}; \gamma, c)$ is a continuous function of Y_{it} bounded between 0 and 1, consequently there are a continuum of states between those two extreme regimes.

Following the work of González et al. (2005) and Colletaz and Hurlin(2006) who also try to check the EKC hypothesis, the transition function is formulated as follows:

$$g(Y_{it}; \gamma, c) = (1 + \exp(-\gamma(Y_{it} - c)))^{-1} \quad \gamma > 0 \quad (2)$$

where c denotes the location parameter or the threshold between the two extreme regimes and γ determines the smoothness of the transition. In order to analyse the non-linear link between GDP per capita and water use per person, the transition variable is assumed to be the logarithm of per capita income in country i in year t . When γ tends to infinity, the transition between the extreme regimes is sharp and the PSTR becomes a panel threshold model (Hansen, 1999). If on the contrary γ tends to zero, the transition

function $g(Y_{it}; \gamma, c)$ is constant and the model collapses into a standard lineal model with country specific effects.

In the context of the “income-water use relationship”, income elasticity is obtained as a weighted average of β_1 and β_2 .

$$\text{PSTR} = (\partial W_{it}) / (\partial Y_{it}) = \beta_1 + \beta_2 g(Y_{it}; \gamma, c) + \beta_2 Y_{it} \partial g(Y_{it}; \gamma, c) / (\partial Y_{it}) \quad (3)$$

As a consequence, when examining the vector β_1 and β_2 we can only interpret the sign of the parameters that mean an increase or a decrease in per capita water withdrawal with per capita income, being necessary to calculate water income elasticities to quantify the relative increase or decrease per unit of income.

Eventually, it is noteworthy that the smooth transition regression is a more general specification of the quadratic polynomial model commonly used to study the EKC. As a result, according to Aslanidis and Xepapadeas (2006), using regime switching models like the PSTR is justified by the fact that polynomial models, usually utilized to test the existence of the EKC, are particular cases of the PSTR.

1.2. Estimation and linearity tests

Before estimating the PSTR it is important to test whether the regime switching effect is statically significant. Testing linearity in equation 1 can be done by testing $H_0: \gamma = 0$ or $H_0: \beta_1 = \beta_2$. In both cases, the test will be non-standard, because under H_0 the model contains unidentified nuisance parameters. In the framework of the PSTR, the solution offered is similar to the one proposed by Luukkonen et al. (1988) for the so-called Davies problem in time series (Davies, 1977, 1987). It consists of approximating the transition function $g(Y_{it}; \gamma, c)$ using the first and second Taylor

expansion around $\gamma = \mathbf{0}$. Then, an equivalent hypothesis in an auxiliary regression is tested (see Aslanidis and Xepapadeas (2006) for more detail). We then obtain:

$$W_{it} = \mu_i + \theta_1 Y_{it} + \theta_2 Y_{it}^2 + \varepsilon_{it}^* \quad (4)$$

$$W_{it} = \mu_i + \theta_1 Y_{it} + \theta_2 Y_{it}^2 + \theta_3 Y_{it}^3 + \varepsilon_{it}^* \quad (5)$$

Therefore, testing linearity is equivalent to testing $H_0: \theta_2 = 0$ in equation 4 and $H_0: \theta_2 = \theta_3 = 0$ in equation 5. If SSR_0 equals the sum of squared residuals under H_0 (lineal panel model with individual fixed effects) and SSR_1 is the sum of squared residuals under H_1 (PSTR model with two extreme regimes), the F statistic turns out to be:

$$LM_F = \frac{SSR_0 - SSR_1}{\left[\frac{SSR_0}{TN - N - 1} \right]} \quad (6)$$

Once we have tested linearity, we proceed with the estimation of the PSTR in equation 1. It consists of two steps. Firstly, fixed effects are eliminated by removing individual-specific means. Taking individual means in equation 1 yields:

$$\bar{W}_i = \mu_i + \beta_1 \bar{Y}_i + \beta_2 \bar{W}_i(\gamma, c) + \bar{\varepsilon}_i \quad (7)$$

Where $\bar{W}_i$, $\bar{Y}_i$, $\bar{W}_i(\gamma, c)$ and $\bar{\varepsilon}_i$ are individual means with

$$\bar{W}_i(\gamma, c) = \frac{1}{T} \sum_{t=1}^T Y_{it} g(Y_{it}; \gamma, c)$$

. Removing equation 7 from equation 1 we obtain:

$$\tilde{W}_{it} = \beta' \tilde{Y}_{it}(\gamma, c) + \tilde{\varepsilon}_{it} \quad (8)$$

Thus, the transformed element $\tilde{Y}_{it}(\gamma, c) = (Y_{it} - \bar{Y}_i, Y_{it}g(Y_{it}; \gamma, c) - \bar{W}_i(\gamma, c))$ depends on the parameters of the transition function γ and c through both the levels and state means. So the vector $\tilde{Y}_{it}(\gamma, c)$ has to be recomputed at each iteration. Given a

couple (γ, c) obtained from a grid search, β_1 and β_2 are estimated by ordinary least squares conditioned on the values of γ and c . Then, in the second step, parameters γ and c are estimated by Non Linear Least Squares (NLS).

An important issue to take into account is the selection of starting values of γ and c , since it notably determines the convergence procedure. To select good starting values, a two-dimensional grid search of 50 values for γ and 100 values of c is carried out. Given these grids, the vector with the minimum residual sum of squares is used to estimate the corresponding β_1 and β_2 .

After estimating, the next phase consists of testing the number of transition functions that must be included in the specification. Thus, we will test the null hypothesis that there is 1 transition function versus the alternative there are 2 transition functions.

$$W_{it} = \mu_i + \theta_1 Y_{it} + \theta_2 Y_{it} g(Y_{it}; \gamma, c) + \theta_3 Y_{it}^2 + \varepsilon_{it}^* \quad (9)$$

$$W_{it} = \mu_i + \theta_1 Y_{it} + \theta_2 Y_{it} g(Y_{it}; \gamma, c) + \theta_3 Y_{it}^2 + \theta_4 Y_{it}^3 + \varepsilon_{it}^* \quad (10)$$

In this case, the null hypothesis will be $H_0: \theta_2 = 0$ in equation 9 and $H_0: \theta_3 = \theta_4 = 0$ in equation 10. This recursive procedure continues until H_0 is not rejected.

Subsequently,, we apply the instrumental variable extension of the PSTR model (IV-PSTR) proposed by Fouquau et al. (2008) and Lee and Chiu (2011). Following Lee and Chiu (2012) we will take the lagged value of the explanatory variable as instrumental variable, $Z_{it} = Y_{it-1}$. Then, $\bar{Z}_{it}(\gamma, c) = (Z_{it} - \bar{Z}_i, g(Y_{it}; \gamma, c) - \bar{g}(\gamma, c))$,

where $\bar{Z}_t = \frac{\sum_{i=1}^T Z_{it}}{T}$ and $\bar{\zeta}(y, c) = \frac{\sum_{i=1}^T Z_{it} g(Y_{it}; y, c)}{T}$. As before, $Z_{it}(y, c)$ and $Y_{it}(y, c)$ have to be recalculated at each iteration. Consequently, given (y, c) the parameters will be obtained by instrumental variables as follows:

$$Y_{it}^*(y, c) Z_{it}(y, c) = \alpha [Z_{it}^*(y, c) Z_{it}(y, c)]$$

Then, during the second stage, the parameters of the transition function Y and c are estimated by Non Linear Least Squares conditionally to $\bar{\beta}_{IV}(y, c)$.

So far, our model only examines the effect that income per person exerts on the dependent variable, keeping all other factors determining per capita water withdrawal constant. However, there are many other elements influencing per capita water use. Thus, in order to reduce the possible omission variable bias, as well as quantifying some of the factors affecting per capita water use, we add two control variables. The first one, the annual average precipitation volume (precipitation) is used as a proxy for water availability. As water scarcity is usually a regional problem, we aim to capture climatic regional differences, particularly as far as water resources are concerned. The introduction of this variable is justified by the fact that those areas with greater water scarcity tend to use their resources in a more efficient way (Gleick, 2000). Thus, the variable precipitation is expected to show a positive sign. Secondly, some authors focus on the differences in environmental management depending on political and social conditions in different countries. Some of them argue that an improvement in democracy entails a development of environmental performance and consequently a lower level of natural resources use and environmental damage (Wislow, 2005; Li and Revenue, 2006). For that reason, we try to control for institutional differences by adding a variable called political freedom (PF). On the basis of the information provided by

Freedom House, we use this qualitative variable ranking from 1 (representing the most political free to 7 the least free). Accordingly, PF is expected to display a positive coefficient, that is, the higher PF index or the less politically free a country is, the more water per person is withdrawn. Given these control variables the model is written as:

$$W_{it} = \mu_1 + \beta_1 Y_{it} + \beta_2 Y_{it} g(Y_{it}; \gamma, c) + \beta_3 Precip_{it} + \beta_4 PF_{it} + \varepsilon_{it} \quad (12)$$

The variable precipitation is expressed in logarithms, whereas PF is introduced in levels.

2. Data and Empirical results

In this study, we use a dataset of water withdrawal in 65 countries over the years 1960, 1970, 1980, 1990, 1995, 2000 and 2008¹. The dataset comes from UNESCO and was prepared for the Comprehensive Assessment of the Freshwater Resources of the World in the framework of the International Hydrological Programme (IHP) of UNESCO. Per capita water use is the ratio of water use to population. Per capita national income is measured by per capita GDP in Geary-Khamis 1990 U.S. \$ on a Purchasing Power Parity basis. Population and per capita income data come from Maddison (2010). Table I reports some descriptive statistics. As can be seen, we have 455 observations for each variable, with per capita income ranging from 217 to 31,177 U.S. \$ of 1990 and a mean of 5,232 U.S. \$ of 1990 and water use per capita between 2.41 and 205,224 Dm³ per person. Political Freedom is a variable that assigns a numerical rating from 1 to 7 for both political rights and civil liberties, with 1 representing the most free and 7 the least free. The average of the political rights and

¹ Although the database provides information for 79 countries, as Hansen (1999) notes, it is unknown if this methodology can be extended to unbalanced panels. In this context, our option is to restrict the sample to 65 countries.

civil liberties ratings, known as the freedom rating, determines the overall status: Free (1.0 to 2.5), Partly Free (3.0 to 5.0), or Not Free (5.5 to 7.0) (Freedom House). Precipitations are measured in $10^9 \text{ m}^3/\text{year}$ and have a mean of $1303.3 \cdot 10^9 \text{ m}^3/\text{year}$ (AQUASTAT).

Insert table I

This section displays two kinds of estimations. On the one hand, a polynomial model with fixed effects, as the ones commonly used to examine the EKC, is applied. On the other hand, the PSTR previously explained, will be employed.

Before estimating, it seems convenient to ensure whether our variables have unit roots or not, since to avoid spurious regressions all the variables in the model must be stationary. To this end, we utilize unit root tests for panel data. Table II reports Maddala and Wu's (1999) panel unit root test together with Pesaran's (2007) panel unit root test that accounts for cross sectional dependence in the dataset. The results of table II lead to the rejection of the null hypothesis of a unit root. Consequently, both per capita income and per capita water use are $I(0)$, i.e., our variables do not have a unit root.

Insert table II

Once the suitability of the variables is tested, we estimate the “water withdrawal-income per capita” relationship using a polynomial panel model (table III) with individual effects and time dummies. It is important to note that both heteroskedasticity and autocorrelation have been detected. Therefore we have applied PCSE, that is to say, we have calculated panel-corrected standard errors (PCSE) and then estimate the following model.

$$W_{it} = \mu_i + \tau_t + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 Precip_{it} + \beta_4 PF_{it} + u_{it} \quad (13)$$

The coefficient of income appears to be positive and significant at 1%. This parameter is high and superior to 1. In the second place, the parameter of income squared is clearly negative and again significant at 1%. In this case, its value is small, reaching -0.09. According to these results, water use seems to follow a growing trend with a steep slope for low income values. As income rises, the slope turns gentler until an income per person of 818 U.S. \$, from that moment, a continuous fall can be seen. Precipitation shows positive elasticity, indicating that the higher water endowment a country has, the more water per person is used. Moreover, PF coefficient is 0.723, meaning that when the political freedom index increases (that is, when political freedom falls) per capita water use tends to rise.

Insert table III

Now let's move to the PSTR model. The first step involves testing whether the regime switching is significant or not. If linearity is rejected, then we have to determine the number of transition functions to capture all the heterogeneity. In table IV we can see the F-statistics and p-values of the tests of linearity versus PSTR, as well as of the non remaining linearity. The linearity test leads to the rejection of the linear "per capita water use – income per person" relationship. In addition, we can conclude that a model with only a transition function is enough to capture the non linear behavior of the data, since the hypothesis of two regimes (one optimal transition function) is not rejected.

Insert table IV

Insert table V

Therefore, a PSTR model with one transition function seems to be appropriate to capture the heterogeneity of the data. Table V shows the estimated models (model 1 to

model 3) with individual fixed effects that capture country specific features such as climate or water endowments and with temporal dummies to control for time varying aspects like exogenous technological development, productive structure, or consumer society². Table V also includes t-ratios corrected for heteroskedasticity. Recall that only the signs of the estimated parameters $\text{Income } \beta_{1,1}$ and Income as transition variable $\beta_{2,1}$ can be interpreted, whereas both the sign and the value of precipitation $\beta_{1,2}$ and PF make sense $\beta_{1,1}$. From table V we observe that income coefficient $\beta_{1,1}$ is always significant positive, whereas the parameter of the transition variable $\beta_{2,1}$ is always negative, and higher than $\beta_{1,1}$ in absolute value. This simply means that, for low income values, when the threshold variable (per capita income) grows, the “per capita income-per capita water withdrawal” relationship although positive, tends to decrease. For medium and high incomes the link is negative. The estimation of the slope parameter is small in all the cases, indicating that the transition between the two extreme regimes is not sharp and therefore the “water use-per capita income” relationship cannot be considered as a limited number of regimes but as a continuum of regimes. In sum, we could say that per capita water withdrawal increases with low per capita income. However from a turning point, water withdrawal peaks and the “water use-income” link tends to be negative. This pattern is displayed in figure 1, where per capita income is plotted against the estimated per capita water use derived from the PSTR model. In this regard, it is important to say that the value of fitted per capita water withdrawal cannot be interpreted, since as we are interested in the association between these two variables, we have omitted fixed effects. In a first step, the increase in

² Coefficients are positive and increase over time, that is, they show a trend.

income produces a sharp growth in water use, however as countries develop, the more income the less water withdrawal per person. Finally, a deceleration in the de-growth takes place. In this regard, it is important to note that the former does not mean that a real decrease in per capita water use takes place for medium and high GDP values, but that the relationship between per capita income and water use per habitant is negative when all other factors determining water withdrawal per person keep constant. Besides, all countries do not follow exactly the same trajectory, since as stated by De Bruyn et al. (1998), the EKC is a descriptive relationship trying to measure the association between two variables, so, some nations may not follow the estimated pattern and consequently the general turning point may not match up with the actual of individual countries.

As we said before, to improve the possible omission variable bias we have estimated PSTR controlling for availability of water resources and for the quality of institution (model 3). From table V we can see how the estimates of income β_1 and income as transition variable β_2 are rather similar in the three models presented. Moreover, as expected sign of the parameter precipitations β_3 is positive, indicating that a 1% increase in annual average level of precipitation involves a 5.02% rise in per capita water use. Likewise, as previously indicated the parameter β_4 associated with political freedom equals 0.74. This shows that a higher political freedom index (i.e., less political freedom) implies more per capita water use, in other words, an increase in democracy entails less use of water resources per person.

Insert figure 1

Insert figure 2

Figure 2 illustrates the scattered graph of the logistic transition function against per capita income. There are only few observations within the low extreme regime $g(Y_{it}; \gamma, c) = 0$ and no observations within the upper extreme regime $g(Y_{it}; \gamma, c) = 1$. Nonetheless, the transition phase contains most of the data, what clearly displays the large heterogeneity on the sample and again reminds the need of using the PSTR model.

In sum, estimates reach the same general conclusion; there exists a positive link between per capita water withdrawal and per capita income for low income levels. From this threshold, the impact of per capita income on water use per person is significantly negative, that is, a rise in per capita income involves a drop in the quantity of water used per person all other things being equal or held constant. Nevertheless, as we will see later (figure 4), on average, the value of income elasticity is somehow divergent, depending on the model chosen (quadratic or PSTR).

Once we have estimated the parameters, it is possible to obtain the time varying individual income elasticity of water use for each country and period. Equation 3 gives the formula to calculate income elasticity of the PSTR model. The elasticity of a homogeneous quadratic polynomial model is given by the expression:

$$e_{it}^{quadratic} = \frac{\partial W_{it}}{\partial Y_{it}} = \beta_1 + \beta_2 Y_{it} \quad (14)$$

Therefore, income elasticity varies depending on both the year and the country in the PSTR model and quadratic polynomial model. However, it is important to take into account that this fact is due to different reasons. As we can see in (14), income elasticity in the quadratic fixed effects regression depends on the value of the

parameters β_1 and β_2 as well as on the value of per capita income. That is, as the estimated β are common for all countries and periods in this model, the individual and time variability of $e_{it}^{quadratic}$ will be determined by per capita GDP. On the contrary, if we examine e_{it}^{PSTR} (equation 3), apart from income, the variability in elasticity stems from the transition function. Figure 3 reports the link between per capita income and the PSTR income elasticity. The association is clearly non-linear, more concretely, elasticity appears to be inversely correlated with per capita GDP; nonetheless, this decreasing trend tends to steady for the highest income observations.

Insert figure 3

Income elasticity is time varying, so table VI reports the individual average elasticities based on the historical values of per capita income for the polynomial model, the PSTR model, the instrumental variables PSTR model, and the PSTR with control variables. The average standard deviations are also included. The individual average is obtained as follows:

$$\bar{e}_i = \frac{1}{T} \sum_{t=1}^T e_{it} \quad SE = \sqrt{\frac{1}{T} \sum_{t=1}^T (e_{it} - \bar{e}_i)^2} \quad (15)$$

Insert table VI

In general, the PSTR and quadratic elasticities tend to be quite similar in most cases (quadratic polynomial elasticities are slightly higher), what could bear out that the PSTR is a good approximation of the quadratic fixed effects model. However, as linearity was rejected in table IV, we find that the PSTR is the optimal model to account for the heterogeneity in the data, and therefore, in the following we will focus on the values of the former estimates.

On the whole, there seem to be significant differences among countries. Looking at table VI, we observe that the average income elasticities of water use are rather diverse. For example, in the PSTR model, the estimated values range from -0.59 of United States to 0.07 of Zaire, what clearly illustrates the great heterogeneity of the sample. On global average, water use income elasticity is -0.24. The countries that are below average have the highest per capita income levels and belong mainly to North America (Canada or EE.UU.), Oceania and Europe (Sweden or France among others), with no African country in this situation. Many of these developed areas reach elasticity values around -0.6 at the end of the period studied.

The vast majority of nations above average are African or Asian and its mean income is less than 3,029 1990 U.S. \$. In this heterogeneous group it is possible to find different patterns. On the one hand, countries such as India or China that in 1960 displayed positive elasticities, have followed a decreasing trend and exhibit negative values around -0.3 nowadays. On the other hand, we find states like Madagascar or Haiti that have adopted the opposite pattern, from negative to positive elasticities. Finally, those with the lowest income (from Bangladesh to Zaire) are outstanding, since they display positive elasticities during all the period, that is, from 1960 to 2008 the relationship between water withdrawal and income is direct and even growing in places like Zaire.

As well as taking into account heterogeneity, one of the key points of the PSTR model is that it allows examining temporal dynamics of the dataset. Thus, in order to analyze trends in the water use-income link, the global average of the results obtained in polynomial, PSTR, IV-PSTR and PSTR control estimates are plotted in figure 4. As shown in figure 4, the income elasticity of water use is, on global average, negative and

decreasing. The global path is clear, there is a continuous decrease of income elasticity from 1960, i.e., the “income-water withdrawal” relationship is negative, and tends to decrease with time. On global average, the reduction in income elasticity is particularly intense from 1960 to 1980, given that from this moment the reduction continues but at a slower pace. It is also noteworthy the fact that on average PSTR , IV-PSTR and PSTR control elasticities are very close; nevertheless, and in spite of following a similar path, the polynomial elasticity is rather divergent in value.

Insert figure 4

3. Discussion

Several recent papers (Kander et al., 2004; Gales et al., 2007) carry out the assessment of the EKC in a long run framework, giving a historical and comprehensive overview of the relationship between economic growth and environmental impacts or energy consumption. In our case, it is not possible to obtain data prior to 1960 for a wide set of countries. Nonetheless, it seems viable to put in context our results with the trajectory of global water use, or some regional groups, from 1900.

Insert figure 5

Figure 5 plots a curve with a sharp upward limb between 1900 and 1960, a slower growth until 1980 and a smooth fall from this moment. A less aggregate analysis by continents (table VII), confirms, broadly speaking, this result; clearly corroborating the decrease in per capita water use from 1980 to 1990 in all of them and the previous growth.

Insert table VII

All these data would suggest the existence of a rising limb for low income values. That is, if we had individual data for the whole XXth century and we could analyze the link between per capita income and per capita water use graphically as seen in figure 5, it would be possible to distinguish a lengthy and steep growing trend and a small and smooth falling limb. Thus, the gradual growth of the first half of the twentieth century would dominate the association and we could probably assert the presence of a more complete EKC. Nevertheless, such a statement is not possible based on our estimates from 1960.

Accordingly, at the lowest levels of per capita income, more income seems to boost water use. As said by Goklany (2002), in this step the highest priority consists of meeting basic needs without paying attention to environmental damage. In the particular case of water resources, per capita income affects freshwater use from different perspectives. First of all, improvements in standards of living entail changes in dietary patterns, moving towards more water intensive goods such as meat or fruit, what is possible due to the extension of irrigation and the construction of water infrastructure. In addition, the development of the industrial sector together with the growing urbanization, imply a great and diverse increase in per capita water use (Duarte et al., 2011).

As per capita GDP increases, water use income elasticity turns out to be negative, i.e., more affluence means less water withdrawal per habitant. According to Duarte et al. (2011), the combination of technical, managerial and institutional developments, improve the efficiency of water use. We could point at advances in environmental regulation, the perception of health risks, improvements of irrigation systems or economic constraints, among other factors. We concur with Stern (2004)

who, when talking about emissions, says that innovations are adopted in high-income countries first and with a shot lag before they are implemented in many emerging countries, allowing emission drops in both developed and developing countries at the same time. Therefore, improvements such as micro irrigation or water pricing seem to be put in practice first in developed areas and subsequently transferred to countries with less per capita GDP, giving place to substantial reductions or stabilizations in water use per capita, in both developed and developing areas. That way, countries such as Mexico, Malaysia or Poland, among others, show similar negative elasticities values in 2008 to the ones of developed countries like France, United States or Australia in 1960. In this regard, we should consider the temporal framework we are working with; if data for the whole twentieth century were available our results would probably change. That is, as we said before the growing trend of the link would be steeper and developing countries could not have taken advantage of technological advances taken place in developed areas from the seventies. Consequently, as the growing limb would dominate the curve, the least developed countries would reach negative elasticity at higher income levels. Finally, the areas with highest GDP per capita also show negative elasticities, however as these countries become wealthier, the decrease produced in water use due to an increase of per capita GDP tends to be smaller. Measures like the Clean Water Act in the United States or the introduction of new irrigation techniques had an important initial impact, leading a notable decrease in water use; nonetheless their original effect appears to flatten as time goes by. Despite this fact, some authors like Gleick and Palaniappan (2010) refer to the concept of peak water, meaning that some developed countries, like for instance the United States, have little leeway for the expansion of water withdrawal. Mainly, they refer to agriculture, responsible for around 80% of global water use, and say that it appears difficult a greater enlargement of agriculture in high-income countries, particularly in arid areas, where water resources and land are no longer available or their use appears to be ecologically and economically unsustainable.

Therefore, following this reasoning, we could say that although the fall in water use levels out in the majority of developed countries, some factors seem to indicate that it is unlikely that per capita water use rises sharply again.

4. Conclusion

In this paper we have assessed the “water use-income” relationship (in per capita terms) in 65 countries from 1960. To that aim, we have estimated different models; a quadratic polynomial fixed effects model, a Panel Smooth Transition Regression, the late Panel Smooth Transition Regression with lagged per capita income as an instrument and a Panel Smooth Transition Regression with control variables. The four of them lead to a similar conclusion, what corroborates the robustness of the results. Firstly, there exists a non-linear link between per capita water use and income. When plotting these two variables, they seem to represent a peculiar inverted-U shape, i.e., water use tends to increase with the lowest income observations but this trend reverses when income becomes greater, being the downward limb prevailing. As far as this relationship is concerned, it is important to highlight that a negative link between per capita income and water use per person does not mean that the per capita use of water resources decreases, but that the more income per capita the less use of water resources keeping the other factors influencing water use constant. Moreover, the value of the smoothness parameter indicates that the transition is slow. Secondly, the variability in income elasticity of water use reflects the large heterogeneity in the sample. Elasticity is positive when income is low and negative as income grows. Eventually, if we look at the global trajectory of income elasticity, there is no doubt that it decreases as time goes on.

This fall is particularly sharp until the eighties but tends to be flatter for the highest income levels. The volume of water resources of a country (precipitations used as a proxy) is positively significant to explain per capita water use; therefore, those countries with water scarcity tend to be more efficient and use less water per person. Eventually, higher levels of democracy appear to trigger better environmental institutions and thus, less water use per capita.

As a result, is there an Environmental Kuznets Curve for water use? Following Kander and Lindmark (2004), who offer an EKC examination in the long run and taking into account the great increase seen for per capita water use during the first half of the twentieth century, together with the previous estimates which show a negative water use-income link, it would be possible to distinguish an upward and a downward limb. However, the results of this study, with information from 1960, only allow us to state that there exists a peculiar EKC with a marked falling trend that dominates the link. As seen in Duarte et al. (2011), at the same time economic development entailed pressures on water resources, technological innovations and institutional changes were introduced in both, developed and emerging nations, making up for income increases. In this respect, it is important to note that although an increase in water use (in absolute terms) can be observed for the vast majority of areas, representing a growing pressure on the resource, our findings appear to suggest a negative link between per capita GDP and per capita water withdrawal keeping all other factors constant. In this sense, the trajectory of variables such as population or technology, among others, could be decisive to explain the trend followed by water withdrawal seen in Duarte et al. (2011). Obviously, despite innovations have been adopted in developing countries with relatively short lags

regarding most developed areas; there is still a lot to do, since it exists a wide margin of action around key issues such as water pricing or water metering, particularly in agriculture. These aspects have a crucial nature for the continuation of the decreasing path of the “per capita water use - per capita income” nexus, because, as we have previously seen, the decline in income elasticity keeps becoming smoother as income grows and the pressure on the resource is increasing in many areas of the world.

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Table I: Summary statistics

	Per capita GDP	Per capita water use	Precipitations	Political freedom
Mean	5,232	4,796	1303	3.3
Standard error	5,652	20,675	2474	1.8
Maximum	31,177	205,224	15,174	7
Minimum	217	2.4	6.1	1
Observations	455	455	455	455

Source: own calculations based on UNESCO

Per capita water use is measured in Dm^3 per person.

Per capita GDP in 1990 Dollars per person.

Precipitations are measured in $10^9 \text{ m}^3/\text{year}$.

Table II: Unit Root Tests

Maddala and Wu's (1997) ADF Unit Root Test		
	Per capita GDP	Per capita water use
Intercept	571.4 ^{***} (0.0000)	583.0 ^{***} (0.0000)
Intercept and trend	190.0 ^{***} (0.0005)	310.9 ^{***} (0.0000)
Pesaran 's (2007) CIPS Unit Root Test		
	Per capita GDP	Per capita water use
Intercept	-6.972 ^{***} (0.0000)	-7.381 ^{***} (0.0000)
Intercept and trend	-5.987 ^{***} (0.0005)	-7.145 ^{***} (0.0000)

P-values in parenthesis. *** 1% significant level.

The null hypothesis is that the panel has a unit root

Table III: Water use-income relationship. Panel model with time and individual fixed effects

Parameters		
β_1 Income	1.245***	(2.95)
β_2 :Income squared	-0.0928***	(-3.43)
β_3 :Precipitations	2.347 ***	(5.41)
β_4 :PF	0.7238***	(5.41)
Turning point	818.34 1990\$	

The dependent variable is log per capita water use. All variables are in logarithms, except for PF.

Values in parenthesis are t-ratios. ***, **, * stand for 1%, 5% and 10% significant level.

Table IV: Linearity and non remaining heterogeneity tests

Linearity test vs. PSTR	PSTR Model(1)	PSTR-IV Model(2)	PSTR-control Model(3)
H_0 : 1 regime (no transition function)	F= 12.80766	F= 12.95102	F=13.58784
H_A : 2 regimes (1 transition function)	P-value= 3.88815e-04	P-value= 3.61036e-04	P-value= 2.59969e-04
No remaining STR-type nonlinearity			
H_0 : 2 regimes (1 transition function)	F= 0.01750	F= 4.92599e-04	F= 0.00642
H_A : 3 regimes (2 transition functions)	P-value=0.89483	P-value= 0.98230	P-value=0.93620

Statistics are reported until the non rejection of H_0

Table V: Parameter estimation of the PSTR

Variables	PSTR Model(1)	PSTR-IV Model(2)	PSTR-control Model(3)
B_1 :Income	0.314** (1.99)	0.3698** (2.169)	0.346** (2.13)
B_2 : Income	-0.595*** (-3.39)	-0.678*** (-3.46)	-0.785*** (-3.50)
Transition variable			5.02*** (3.66)
B_3 : Precipitacion			0.742*** (5.58)
B_4 : PF			
c	10.53 (antilog 37,697.10)	10.64 (antilog 42,048.65)	11.42 (antilog 91,126.26)
γ	0.45	0.414	0.382
RSS	39.898	39.858	39.426
AIC	-2.39001	-2.39099	-2.39312
BIC	-2.29945	-2.3044	-2.28445

Values in parenthesis are t-ratios.

, * stand for 5% and 1% significant level.

Standard errors corrected for heterokedasticity.

Table VI: Individual average of income elasticity of water use

	Average GDP p.c.	Quadratic		PSTR		IV PSTR		PSTR control	
	(\$1990)	$\bar{e}_{it}$	$\bar{\sigma}$	$\bar{e}_{it}$	$\bar{\sigma}$	$\bar{e}_{it}$	$\bar{\sigma}$	$\bar{e}_{it}$	$\bar{\sigma}$
Afghanistan	660.5	0.03	0.03	0.02	0.02	0.03	0.03	0.02	0.02
Albania	2,366.1	-0.18	0.06	-0.18	0.06	-0.18	0.06	-0.18	0.06
Algeria	2,743.5	-0.21	0.03	-0.21	0.03	-0.21	0.03	-0.21	0.03
Argentina	7,707.9	-0.39	0.04	-0.41	0.04	-0.41	0.04	-0.41	0.05
Australia	16,042.6	-0.51	0.06	-0.55	0.07	-0.55	0.07	-0.57	0.08
Bangladesh	695.1	0.03	0.04	0.01	0.04	0.02	0.04	0.01	0.04
Bolivia	2,316.9	-0.18	0.03	-0.18	0.03	-0.18	0.04	-0.18	0.03
Brazil	4,447.1	-0.29	0.06	-0.30	0.07	-0.30	0.07	-0.30	0.07
Burkina Faso	797.9	0.00	0.03	0.00	0.02	0.00	0.03	-0.01	0.02
Canada	16,630.6	-0.52	0.06	-0.56	0.07	-0.56	0.07	-0.58	0.08
Colombia	4,307.0	-0.29	0.06	-0.29	0.06	-0.29	0.06	-0.30	0.06
Costa Rica	4,836.8	-0.31	0.06	-0.32	0.07	-0.32	0.07	-0.32	0.07
Cuba	2,457.7	-0.19	0.04	-0.19	0.05	-0.19	0.05	-0.19	0.05
Chad	482.0	0.09	0.04	0.06	0.03	0.07	0.03	0.06	0.03
Chile	7,186.8	-0.37	0.07	-0.40	0.08	-0.40	0.08	-0.40	0.09
China	1,824.4	-0.14	0.15	-0.14	0.15	-0.14	0.15	-0.15	0.15
Dominican Republic	2,445.5	-0.19	0.07	-0.19	0.08	-0.19	0.08	-0.19	0.08
Ecuador	3,442.7	-0.25	0.04	-0.25	0.04	-0.25	0.04	-0.25	0.04
Egypt	2,094.4	-0.16	0.08	-0.16	0.08	-0.16	0.08	-0.16	0.08
El Salvador	2,347.3	-0.18	0.03	-0.18	0.03	-0.18	0.03	-0.18	0.03
France	15,153.7	-0.50	0.07	-0.54	0.07	-0.54	0.07	-0.56	0.08
Guatemala	3,394.8	-0.25	0.04	-0.25	0.05	-0.25	0.05	-0.25	0.05
Haiti	900.5	-0.02	0.04	-0.02	0.03	-0.02	0.03	-0.02	0.03
Honduras	1,835.4	-0.14	0.03	-0.13	0.03	-0.13	0.03	-0.14	0.03
India	1,320.8	-0.08	0.08	-0.08	0.08	-0.08	0.08	-0.08	0.08
Indonesia	2,230.5	-0.17	0.10	-0.17	0.10	-0.17	0.10	-0.17	0.10
Israel	11,282.4	-0.45	0.08	-0.48	0.09	-0.49	0.09	-0.50	0.10
Italy	13,440.1	-0.48	0.07	-0.52	0.08	-0.52	0.09	-0.53	0.09

Jamaica	3,484.2	-0.25	0.02	-0.25	0.03	-0.25	0.03	-0.25	0.03
Japan	13,739.1	-0.49	0.11	-0.52	0.12	-0.52	0.12	-0.54	0.13
Jordan	3,684.9	-0.26	0.06	-0.26	0.06	-0.26	0.06	-0.26	0.06
Lebanon	3,029.0	-0.23	0.05	-0.23	0.05	-0.23	0.05	-0.23	0.05
Liberia	1,123.3	-0.06	0.03	-0.05	0.03	-0.05	0.03	-0.06	0.03
Madagascar	874.8	-0.01	0.04	-0.02	0.04	-0.01	0.04	-0.02	0.04
Malaysia	4,478.3	-0.29	0.12	-0.31	0.14	-0.30	0.14	-0.31	0.14
Mali	752.2	0.01	0.04	0.00	0.04	0.01	0.04	0.00	0.04
Mauritania	981.4	-0.03	0.04	-0.03	0.03	-0.03	0.03	-0.04	0.03
Mexico	5,642.0	-0.33	0.05	-0.35	0.06	-0.35	0.06	-0.35	0.07
Morocco	2,241.7	-0.17	0.06	-0.17	0.06	-0.17	0.06	-0.17	0.06
New Zealand	13,480.5	-0.48	0.04	-0.52	0.04	-0.52	0.04	-0.53	0.05
Nicaragua	1,784.7	-0.14	0.05	-0.13	0.05	-0.13	0.05	-0.13	0.05
Niger	614.0	0.05	0.04	0.03	0.03	0.04	0.04	0.03	0.03
Nigeria	1,143.7	-0.06	0.03	-0.06	0.03	-0.05	0.03	-0.06	0.03
Panama	4,564.2	-0.30	0.06	-0.31	0.07	-0.31	0.07	-0.31	0.07
Peru	3,770.6	-0.26	0.04	-0.27	0.04	-0.27	0.04	-0.27	0.04
Philippines	2,143.1	-0.17	0.04	-0.16	0.04	-0.16	0.04	-0.16	0.04
Poland	5,608.3	-0.33	0.06	-0.35	0.07	-0.35	0.07	-0.35	0.08
Portugal	8,518.5	-0.40	0.10	-0.43	0.11	-0.43	0.11	-0.44	0.12
Saudi Arabia	7,800.9	-0.39	0.06	-0.41	0.07	-0.41	0.08	-0.42	0.08
Senegal	1,328.8	-0.09	0.01	-0.08	0.01	-0.08	0.01	-0.08	0.01
South Africa	3,912.8	-0.27	0.02	-0.28	0.03	-0.28	0.03	-0.28	0.03
Spain	9,779.1	-0.43	0.11	-0.46	0.12	-0.46	0.12	-0.47	0.13
Sudan	967.8	-0.03	0.04	-0.03	0.04	-0.03	0.04	-0.03	0.03
Sweden	16,026.5	-0.51	0.06	-0.55	0.06	-0.55	0.06	-0.57	0.07
Syria	5,613.9	-0.33	0.07	-0.35	0.08	-0.35	0.08	-0.35	0.08
Tanzania	559.5	0.06	0.03	0.04	0.02	0.05	0.02	0.04	0.02
Thailand	3,608.3	-0.26	0.13	-0.27	0.15	-0.26	0.15	-0.27	0.15
Trinidad & Tobago	10,509.1	-0.44	0.07	-0.47	0.07	-0.47	0.08	-0.48	0.08

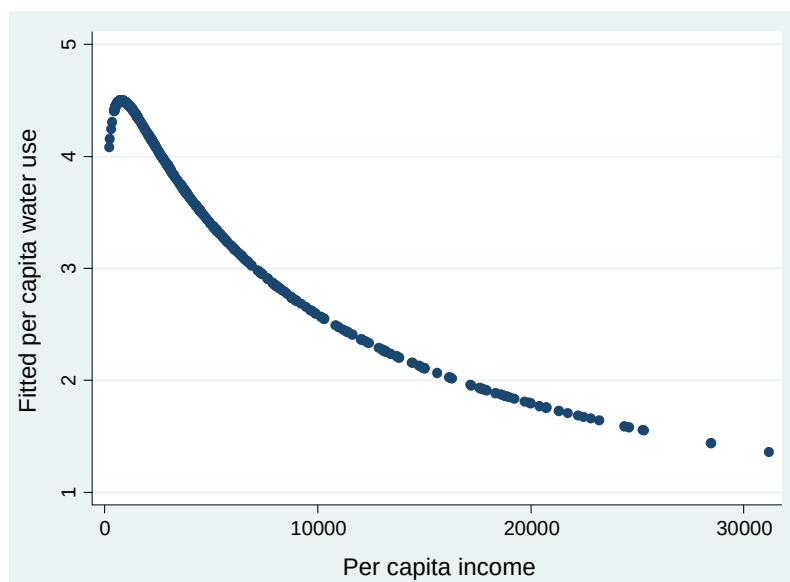
Tunisia	3,053.4	-0.23	0.09	-0.23	0.10	-0.23	0.10	-0.23	0.10
Turkey	4,623.9	-0.30	0.08	-0.31	0.09	-0.31	0.09	-0.31	0.09
Uruguay	6,727.8	-0.36	0.04	-0.38	0.05	-0.38	0.05	-0.39	0.05
USA	20,660.9	-0.56	0.06	-0.59	0.06	-0.60	0.07	-0.62	0.08
Vietnam	1,190.3	-0.07	0.09	-0.07	0.09	-0.06	0.09	-0.07	0.08
Zaire	432.2	0.11	0.09	0.07	0.06	0.08	0.06	0.07	0.06
Ex Soviet Union	5,426.2	-0.33	0.05	-0.34	0.05	-0.34	0.06	-0.34	0.06
Total	3,087.1	-0.23	0.18	-0.24	0.19	-0.24	0.19	-0.25	0.20

Individual average elasticity and standard deviation (%)

Table VIII: Per capita water use average anual growth rates (%)

Region	1900-1950	1951-1960	1961-1970	1971-1980	1981-1990	1991-2000
Europe	2.4	4.9	1.6	2.1	1.4	1.0
North America	1.5	0.6	1.5	0.5	-1.4	-0.3
Latin America	0.1	1.2	-0.5	0.8	-0.3	-0.2
Africa	-0.4	2.6	0.9	0.8	-0.9	1.2
Asia	0.8	1.6	-0.9	-0.3	0.1	-0.3
Oceania	2.8	1.4	1.6	0.5	1.0	-0.2
Ex Soviet Union	0.8	1.1	3.5	4.5	0.2	-2.1

Source: own calculations based on UNESCO

**Figure 1: Per capita income vs. fitted per capita water use**

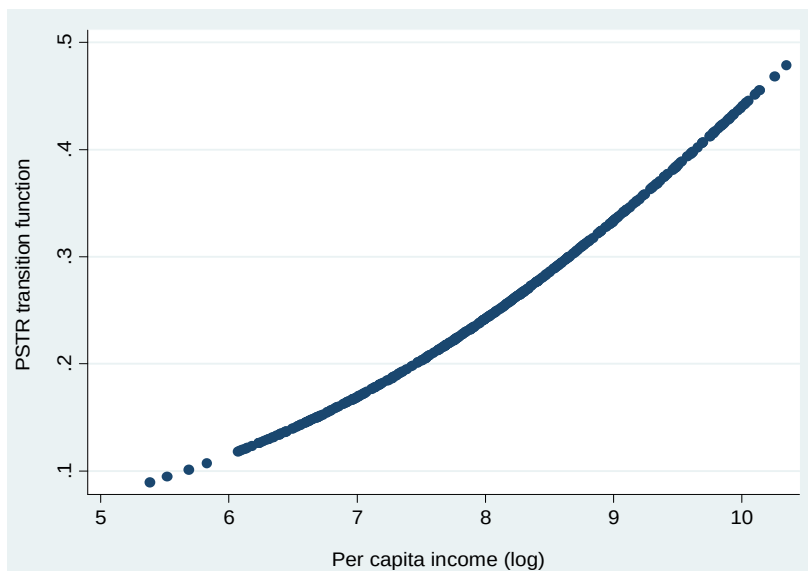


Figure 2: PSTR transition function

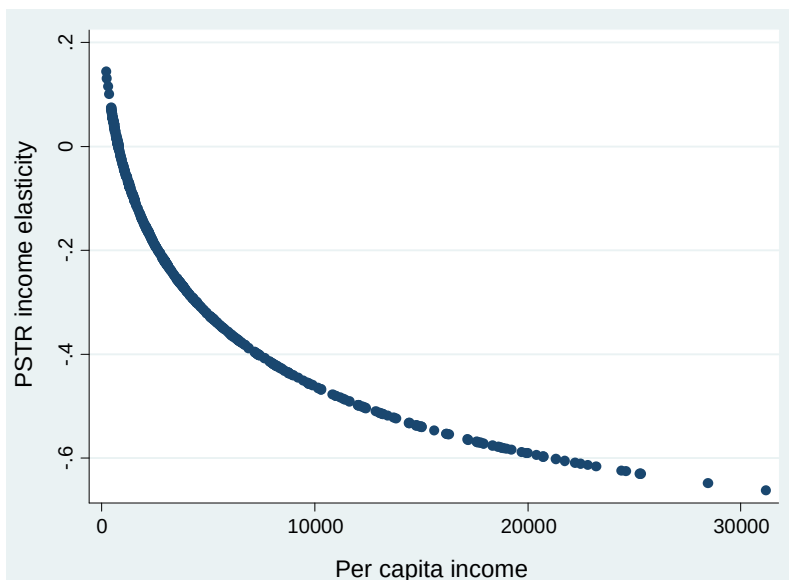


Figure 3: PSTR water use elasticity displayed for all the values of per capita income

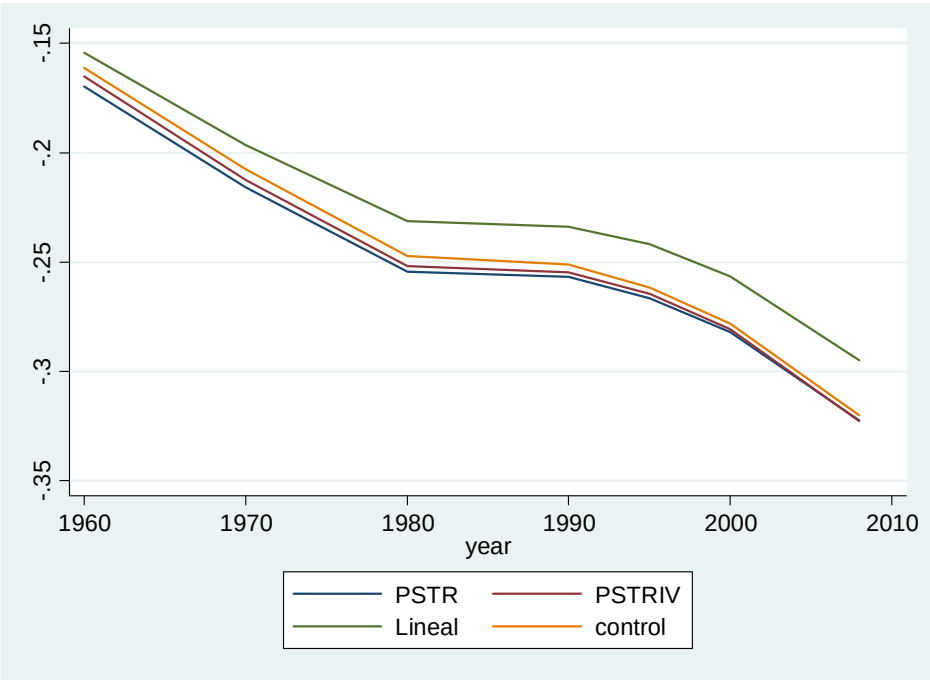


Figure 4: Global time varying elasticities

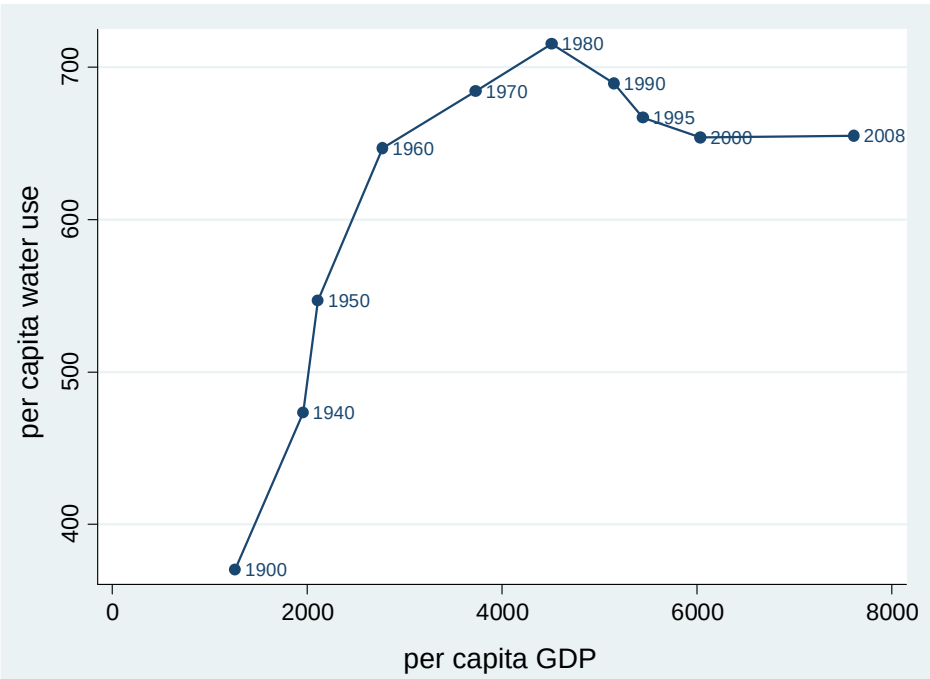


Figure 5: Global average EKC for per capita water use (dm3 yer/per person)

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