Journal of Cleaner Production 88 (2015) 205–213

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

# Water use and economic growth: reconsidering the Environmental Kuznets Curve relationship

David Katz*

*Department of Geography and Environmental Studies, University of Haifa, Mt.Carmel, Haifa 39105, Israel*

ARTICLE INFO

*Article history:*
Received 29 November 2013
Received in revised form
5 August 2014
Accepted 6 August 2014
Available online 3 September 2014

*Keywords:*
Consumption
Economic growth
Environmental Kuznets Curves
Resource use
Water use

ABSTRACT

Predictions of national and global water use have been criticized for being inaccurate and for not taking into consideration economic development. Of the little research that does address water use as a function of economic development, results are inconsistent, but much claims to find clear evidence of an Environmental Kuznets Curves (EKC) or "inverted U" type relationship. This research attempts to elucidate the relationship between income growth and freshwater use by a) evaluating a variety of cross-sectional and panel datasets on water withdrawals and consumptive use, b) employing both traditional least squares and non-parametric regression analysis, the latter of which offers the advantage of not assuming a given functional form, c) testing both per capita and total water use, and d) comparing water withdrawals to consumptive use. The research finds some support for the existence of an EKC, but results are highly dependent on choice of datasets and statistical technique. Results are also sector specific and EKC curves prove to be poor indicators of individual country behavior. As such, the study points to limitations of EKCs in terms of water use policy and planning.



## 1. Introduction

By some estimates, humanity has already appropriated over half of the world's available water resources (Postel et al., 1996). As growth rates for global water consumption continue to outpace even global population growth, several governments, international development agencies and leading researchers have pointed to global water scarcity as a potentially serious economic, health, and even security issue (e.g. (United Nations Economic and Scientific and Cultural Organization (UNECSO), 2009)). Projections of future water scarcity are numerous; however, measurements of actual water use and predictions of future water availability and consumption rates have proven difficult to estimate accurately (Gleick, 2003). Part of the difficulty in such estimates is in identifying the role of economic growth as a factor impacting water use.

Estimates of income elasticity of demand for water for domestic use are commonplace as part of standard demand curve estimations. However, relatively little published literature has examined the relationship between income and water use at the state or national level. Most of the studies that have, provide evidence that national per capita water withdrawals seem to follow an inverted-U or Environmental Kuznets Curve (EKC) type path, with respect to per capita income, by which per capita water withdrawals initially rise and then decline with respect to income.

This paper re-examines this water-income relationship by analyzing multiple cross-sectional and panel datasets, using both traditional least squares and non-parametric density regression techniques. In so doing, it also highlights some unique issues that arise when using natural resource use, rather than pollution levels, as environmental indicators in EKC studies. It confirms limited support for an EKC relationship, but highlights that results are sensitive to choice of dataset, model specification, and econometric technique. In addition, economic growth seems to be a poor predictor of individual country behavior.

The structure of this paper proceeds as follows: Section 2 presents a review of some of the methodologies and objectives of previous EKC and water-income studies, including a brief discussion of some important distinctions between pollution based and resource based EKC studies. Section 3 presents this study's design and rationale. Section 4 presents the results of the analysis of the relationship between national per capita water use and per capita income using international cross-sectional data and panel data for OECD nations and U.S. states. Section 5 extends the analysis of the panel data to cover consumptive use. Section 6 offers a discussion of study results and Section 7 provides conclusions.

* Tel.: +97 2542048694.
*E-mail address:* katzd@geo.haifa.ac.il.

http://dx.doi.org/10.1016/j.jclepro.2014.08.017
0959-6526/

## 2. Water use and income

### 2.1. Natural resources and EKCs

The majority of EKC literature, especially the early literature, has focused on pollution levels as a function of income. This has led to the criticism that such research ignores the natural resource component of environmental quality (Arrow et al., 1995). Of the studies that have examined resource use, the majority have focused on deforestation (e.g. (Koop and Tole, 1999)) or energy (e.g. (Luzzati and Orsini, 2009)). A limited number have focused on water (see the following sub-section). More recently a few studies have conducted broader analysis of material flows as a function of income (e.g. (Vehmas et al., 2007)).

Most of these studies treat resource use as identical to pollution in terms of serving as an indicator of environmental quality. Because, like pollution, much resource consumption provides an economic benefit coupled with an undesired environmental impact, many of the theoretical explanations for the existence of EKCs for natural resources mirror those for pollution (e.g. (Cropper and Griffiths, 1994)). These include, inter alia, increasing income elasticity of demand for environmental quality, economies of scale in resource conserving equipment, outsourcing of environmental impacts (e.g. pollution havens), and structural development type rationales, under which nations' economies develop from agriculturally-based to manufacturing-based, and finally, to a less polluting and less resource intensive service-sector orientation.

Despite these similarities, several characteristics distinguish natural resources from pollution in terms of their relationship to income. This is especially true for resources such as water that tend not to be traded in large quantities internationally. These include (1) limited supplies, and therefore, maximum levels of usage, (2) the role of natural endowments in influencing access to and need for many resources, (3) the fact that natural resources are goods which generally command a positive market price, as opposed to pollution, which is simply an undesired byproduct of production or consumption of other goods, (4) a direct economic cost involved in resource extraction and acquisition, and (5) the fact that, as goods, and not bads, a reduction is not necessarily desirable, certainly not beyond a certain level.

Taken together, these differences might warrant different assumptions about the resources-income relationship. For instance, because we would not expect resource consumption to decline indefinitely and not to reach zero, a model might anticipate a leveling off of per capita consumption at a certain rate. Alternatively, one might anticipate an increase in consumption following a temporary decrease. This could result, for instance, from a temporary effect of a policy intervention, or as a result of a rebound effect, whereby reduced resource conservation due to increased efficiency is eventually overwhelmed by the effective income and price effects that stem from a lower marginal cost of use (Birol and Keppler, 2000). Thus, despite the similarities between resource and pollution based environmental indicators in EKC studies, they should not be assumed to act identically. In practice, however, these distinctions are rarely if ever taken into account.

### 2.2. Water and income

National level income may be expected to influence water use for several reasons. For domestic consumption, positive income elasticity of demand would indicate that as incomes increase, so too does consumption, as water is a normal good. In addition, increases of income may allow for consumption of additional marginal sources of water that may not have been accessible at low income levels (e.g., treatment of brackish water, pumping of deep aquifers, etc.). On the other hand, increased income may result in a decline in water use, as income may allow for more water efficient technologies (e.g., drip-irrigation) and for better maintenance of water delivery systems, and thus, lower levels of water loss due to leakage. Furthermore, countries may phase out of agriculture, the largest consuming sector of water, into less water-intensive sectors such as services. The relative size of each of these effects, and thus, the overall impact of income on water use, however, is not well studied and thus, no assumptions can be made a priori.

While many income elasticity studies exist for domestic sector water demand, only a small number have examined how overall water use correlates with national income. Of these, most have found an inverted U or EKC relationship. Gleick (2003) found no discernable relationship between per capita national water withdrawals and income, however, his study was not a statistical analysis and, in effect, amounted to little more than an eye-balling of the data. Rock (1998) produced the first study to find an EKC for water withdrawals, examining both cross-sectional data for international withdrawals as well as panel data for U.S. state level withdrawals. Rock's analysis, while pioneering, was somewhat problematic.

Rather than attempting to isolate a direct income effect, the original EKC literature used reduced-form models (i.e., they included only income as explanatory variables) to test for overall correlations between environmental indicators and income. As such they reflected both direct and indirect effects of income (Grossman and Krueger, 1995), but did not identify more proximate relationships that may be more causal in nature (Moomaw and Unruh, 1997). Additional variables were intentionally omitted from the early regression equations, because many were seen as endogenous to economic growth (Selden and Song, 1994). Rock included variables such as trade openness that likely suffer from this endogeneity issue. Furthermore, if analysts attempt to isolate the impact of income, they need to develop a comprehensive model that includes all relevant variables, lest they themselves suffer from omitted variable bias. Rock's model was neither a reduced-form, nor was it a comprehensive model. Neither was a later analysis by Barbier (2002).

Cole (2004) used a reduced-form model and Duarte et al. (2013) used a similar model but included a precipitation variable to account for endowment effects. Cole ran fixed effects regressions, as is commonplace in EKC literature, while Duarte et al. ran both fixed effects and panel smooth transition regressions (PSTR) which they claimed are more appropriate for such analysis. Both studies found that national per capita water withdrawals followed an inverted U path. The form of the curve and estimated turning points, however, differed greatly between the two studies.[1]

A few sectoral studies also found support for an EKC for water withdrawals. Jia et al. (2006) and Hemati et al. (2011) found EKCs for industrial water use for several countries. Goklany (2002) presented a qualitative assessment of water use showing that per capita agricultural water withdrawals in the United States seem to display an inverted U form and Bhattarai (2004) found an EKC for irrigated land for tropical countries.

In sum, only a few studies have attempted to look at water use as a function of income at a national or state level. Most of those claim to have found some sort of inverted U type relationship. Issues of appropriateness of model choice, regression technique, quality of data, and/or a focus restricted to a single sector or region, however, raise questions as to the robustness of such findings.

[1] Cole's estimated turning point was between $21,196 and $25,002 (in 1990 US$) depending on the model, while Duarte et al.'s was $818 using a fixed effect model similar to Cole's and slightly over $4000 using PSTR techniques.