Industrial Water Use Kuznets Curve: Evidence from Industrialized Countries and Implications for Developing Countries

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EXTENDED ABSTRACT

Population growth and economic development are the two major driving forces of water demand. In developing countries, the rapid population growth together with an eagerness to develop the national economy, typically through industrialization, has generated a strong demand for additional water. This situation has been the basis underlying many projections of a substantial expansion of industrial water use.

While the increase in industrial water use is a trend evident in many countries, it is also observed that industrial water use in some developed countries has experienced an increase, level-off and then decrease with the economic development and income rises. This inverted U-shaped trend resembles the well-known Environmental Kuznets Curve (EKC). Prior to this study, however, there has been no systematic investigation into changes in industrial water use associated with the process of industrialization.

This paper investigates the existence of the Kuznets curve in industrial water use. It focuses on the following questions: does an inverted U-shaped relationship generally exist between industrial water use and the level of income? If so, where is the turning point of industrial water use? And, what are the preconditions for the decline? Based on the results from the analysis of the OECD countries, preliminary discussion is made for developing countries on the scale of potential increment in industrial water use before reaching the turning point.

A standard EKC model is expressed as a quadratic function of the level of income (Eq. 1). We apply this model to statistically verify the Kuznets curve relationship between industrial water use and income observed in the OECD countries.

$$IW_t = a_o + a_1 Y_t + a_2 Y_t^2 + e_t \qquad (1)$$

The result shows that the relationship between changes in industrial water use and income appears to comply with the Environmental Kuznets Curve, i.e., an inverted U-shaped curve seen in the relationship between income changes and environmental quality. The income threshold corresponding to the turning point of industrial water use varies across the OECD countries with a majority falling in the range of USD10,000 to USD25,000 (1995 constant prices) (Figure 1).

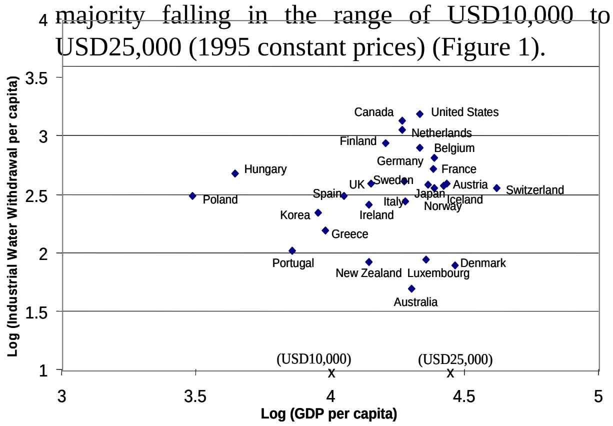

Figure 1. The Peak Industrial Water Use and Corresponding GDP Per Capita in the OECD Countries

The verification of the existence of the industrial water use Kuznets curve helps the prediction of the scale of future increase in industrial water use in developing countries. A large gap is found between the current industrial water use and the projected peak industrial water use in developing countries. The results suggest an importance for developing countries to search for alternative ways of water use to reduce the demand for additional water in the process of industrialization.

1. INTRODUCTION

Water scarcity is becoming increasingly severe in many countries in the world. The World Water Council (Cosgrove and Rijsberman, 2000) estimated that currently about 40 percent of the world population is faced with water shortages. By 2025, the figure will increase to 50 percent. Most of the water-stressed people live in developing countries. It has been a common view that water stress in developing countries will escalate in both magnitude and geographical scope in the coming years (Gleick, 1998; Rosegrant *et al*., 2002; Vörösmarty *et al*., 2000; Alcamo *et al*., 2003; Yang *et al*., 2003).

Population growth and economic development are the two major driving forces of water demand. In developing countries, the rapid population growth together with an eagerness to develop the national economy, typically through industrialization, has generated a strong demand for additional water. This situation has been the basis underlying many projections of a substantial expansion of industrial water use (Zhang, 1999; United Nations Environmental Program, 2002; Clarke, 2003). The bulk of the increase will be in developing countries. The large increase in industrial water use will not only put great pressure on these countries' water resources, but also entail huge financial burdens due to the need for building water supply and wastewater treatment facilities.

While the increase in industrial water use is a trend evident in many countries, it is also observed that industrial water use in some developed countries has experienced an increase, level-off and then decrease with the economic development and income rises (Jia and Kang, 2000; Jia, 2001; Alcamo *et al*., 2003). This inverted U-shaped trend resembles the well-known Environmental Kuznets Curve (EKC). Prior to this study, however, there has been no systematic investigation into changes in industrial water use associated with the process of industrialization. It remains a question as to whether the EKC's paradoxical relationship generally exists between industrial water use and the economic development.

Empirical studies of the EKC have focused on two critical topics: whether a given indicator of environmental degradation displays an inverted U-shaped relationship with per capita income; and the identification of the threshold where environmental quality improves with rising per capita income (Barbier, 1997; Yandle et al., 2004). In this study, we focus on the following questions: does an inverted U-shaped relationship generally exist between industrial water use and the level of income? If so, where is the turning point of industrial water use? And, what are the preconditions for the decline? Based on the results from the analysis of the OECD countries, preliminary discussion will be made for developing countries on the scale of potential increment in industrial water use before reaching the turning point.

In this study, industrial water use follows the definition by Shiklomanov (2000), which includes the water used for cooling, transportation, as a solvent, and as an ingredient of finished products. It does not take into account the discharge after the use in one activity, which may be used by other users. Water use for hydropower generation is also excluded. The corresponding industrial sector is the broad sense of the secondary industry, including mining, manufacturing and thermal power generation. Data for industrial water use are from *World Resources Report* of World Resource Institute (1995-2002). Data for GDP per capita are from *World Development Indicators* of the World Bank (2002).

2. OBSERVATIONS OF THE INVERTED U-SHAPED CURVE IN INDUSTRIAL WATER USE IN THE OECD COUNTRIES

After the Second World War, many western countries had experienced a rapid economic growth and a substantial improvement in incomes. An observation of several developed countries found that their industrial water use had changed alongside income increases.

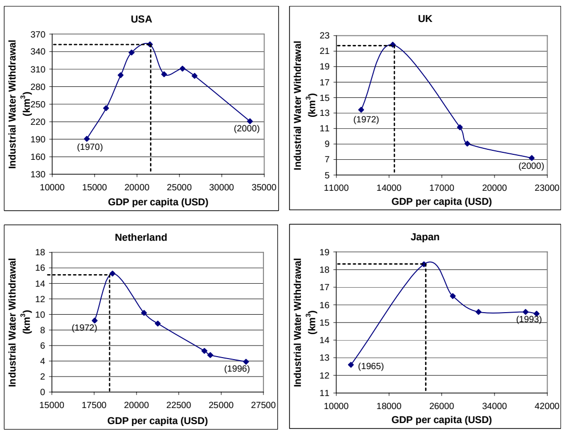

Figure 1. Industrial Water Use vs GDP Per Capita in the USA, Japan, the UK and the Netherlands

Figure 1 shows the situation in the USA, Japan, the

UK and the Netherlands. A relationship described by the Kuznets curve can be observed for all the four countries. With the rise in per capita GDP, industrial water use increased first and then reached a climax. Afterwards, it declined in varying degrees.

The income threshold corresponding to the peak industrial water use, however, varies in the four countries. In the USA, the threshold was about USD21,000/capita (Unless otherwise specified, all the GDP figures in this study are adjusted to the 1995 constant prices). In the UK, it was around USD14,500/capita. The figures in Japan and the Netherlands were around USD25,000/capita and USD18,500/capita, respectively. This situation suggests that there is no unique income threshold that corresponds to the turning point of industrial water use in different countries.

The initial findings encouraged us to investigate further whether or not the Kuznets curve relationship generally applies to all developed countries during industrialization. By examining the trend in the OECD countries, the answer appears to be positive. Except for a few less developed countries, industrial water use in other OECD countries has followed the trend of increase, level-off and then decrease with income rises during the past three to four decades.

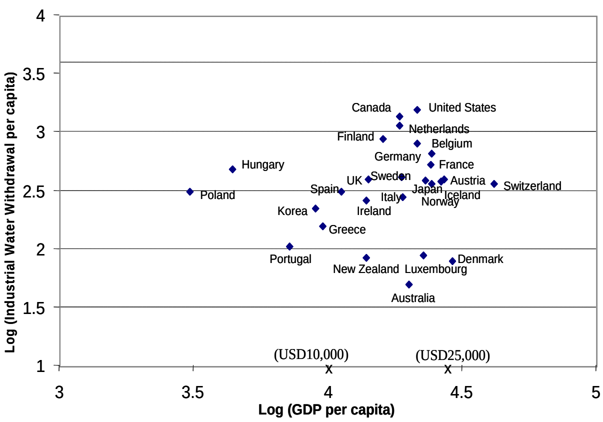

Figure 2. The Peak Industrial Water Use and Corresponding GDP Per Capita in the OECD Countries

Figure 2 shows the peak per capita industrial water use and the corresponding per capita GDP in the OECD countries (excluding Turkey, Mexico and Slovakia due to data inconsistency in different sources). Two features can be observed. The first is that the GDP per capita corresponding to the turning point of industrial water use varies widely. For a majority of the countries, GDP per capita at the turning point falls in the range of USD10,000 to USD25,000. This again suggests that there is no unique income threshold corresponding to the peak industrial water use across countries. The second feature is that the peak volume of industrial water use per capita varies substantially in different countries. In the USA, it is around 1,500 m^3/capita. The figure for Australia is merely 50 m^3/capita. This implies that the actual industrial water use per capita is highly related to country specific conditions.

3. STATISTICAL TESTS OF THE INDUSTRIAL WATER USE KUZNETS CURVE

A standard EKC model is expressed as a quadratic function of the level of income (Stern, 2004). We apply this model to statistically verify the Kuznets curve relationship between industrial water use and income observed in the OECD countries. In the literature, a cubic function of the EKC model is also commonly tested to examine whether the pollution will increase again after the initial decline, i.e., an N-shaped EKC (Canas *et al*., 2003; Groot *et al*., 2004; Stern, 2004). As our interest is to verify the existence of turning point of industrial water use, only the quadratic model is applied. The general form of the model is expressed as:

$$IW_t = a_o + a_1 Y_t + a_2 Y_t^2 + e_t \qquad (1)$$

where IW_t is the quantity of industrial water use (m^3/capita) in year t, Y_t is GDP per capita (USD/capita) in year t; e_t is the error term; a_0, a_1 and a_2 are parameters to be estimated. The values of the parameters, if the EKC hypothesis is valid for industrial water use, should be, for a_1 positive and for a_2 negative. The GDP per capita at the turning point of industrial water use can be found by differentiating Eq (1) and setting it to zero:

$$a_1 + 2a_2 Y = 0 \qquad (2)$$

$$Y = -\frac{a_1}{2a_2} \qquad (3)$$

For individual countries, the available data for industrial water use are discrete with varying time intervals over the period 1960 to 2002. We excluded some countries with very few observations in the analysis. The estimating results for twenty OECD countries are provided in Table 1.

Table 1. Results of Parameter Estimation

Country	a_0	t-test value	a_1	t-test value	a_2	t-test value	R^2	Estimated turning point (USD)	No. of Obs.
Austria	-8939.29	-2.67	857.08	3.29	-15.44	-3.09	0.661	27,750	11
Belgium	-4574.64	-1.13	1110.57	3.03	-24.98	-3.11	0.732	22,230	7
Canada	-432769.70	-1.72	48659.26	1.77	-1265.55	-1.69	0.752	19,220	7
Denmark	24.57	0.03	29.61	0.48	-0.58	-0.57	0.229	25,520	7
Finland	7593.08	2.41	-283.48	-1.06	3.25	0.59	0.756		9
France	-8205.04	-0.68	3409.61	2.88	-79.71	-2.85	0.541	21,390	10
Germany	-34262.68	-1.69	5173.13	3.05	-95.77	-2.81	0.662	27,010	10
Greece	-2242.91	-1.51	480.17	1.61	-23.73	-1.61	0.395	10,120	7
Ireland	-2377.04	-1.98	474.43	2.44	-17.83	-2.44	0.749	13,300	5
Italy	-72418.70	-4.41	9553.62	4.34	-259.74	-3.64	0.903	18,390	9
Japan	8303.06	3.32	570.56	3.32	-9.86	-3.41	0.408	28,930	20
Korea	-427.04	-0.30	740.26	2.00	-36.89	-1.64	0.752	10,030	5
Netherlands	-96628.48	-1.86	10226.16	2.12	-247.76	-2.20	0.401	20,630	9
Norway	1000.88	8.64	53.54	5.11	-1.41	-6.30	0.952	18,960	7
Portugal	1699.33	0.49	395.93	1.16	-27.36	-1.36	0.372	7,240	6
Spain	-14312.36	-1.30	3604.98	2.19	-139.69	-2.15	0.344	12,900	12
Sweden	-5554.74	-0.73	887.87	1.35	-22.58	-1.61	0.797	19,660	11
Switzerland	-21161.07	-1.72	1006.19	1.82	-11.75	-1.81	0.265	42,820	14
UK	-85745.27	-1.84	5980.42	2.42	-505.55	-2.69	0.805	14,550	11
USA	-555311.00	-4.23	76669.82	6.43	-1646.51	-6.37	0.873	23,280	9

Parameters a_1 and a_2 for all the countries, except for Finland, appear to have signs complying with the EKC hypothesis: a_1 is positive and a_2 is negative. The t-test values are statistically significant at 5-10 percent level for most of the estimates. For Finland, the available data cover only the period from 1978 to 2002. The wrong sings of the parameters are caused by a downward trend in industrial water use during this period. This implies that the peak industrial water use in Finland occurred prior to 1978. The regression results provided in Table 1 in general support the existence of the Kuznets Curve relationship between industrial water use and income. For most of the countries, the GDP threshold at the turning point falls between USD10,000/capita and USD25,000/capita. This is consistent with the observations in Figure 2. It is, however, noted that both intercepts (a_0) and slopes (a_1 and a_2) of the industrial water use Kuznets curve vary according to country. The results suggest that although the EKC relationship between industrial water use and GDP per capita holds for the countries observed, the actual pattern of the curve is country specific. Because of the wide range of income threshold, an average GDP per capita in the OECD countries is of little use for predicting the turning point of industrial water use in developing countries.

It should be pointed out that panel data approach has been widely applied in the EKC modeling. Such an approach determines a common turning point for an environmental/pollutant indicator across certain geographical units, e.g., countries and regions. Following the commonly used Kuznets Curve model with panel data application, a model for testing industrial water use Kuznets curve can be specified as:

$$IW_{it} = a_i + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \varepsilon_{it} \qquad (4)$$

where IW_{it} is the quantity of industrial water use for country i in year t; Y_{it} is the per capita GDP for country i in year t; e_{it} is the error term; a_i is intercept for country i, β_1 *and* β_2 are the coefficients of GDP per capita and the square value of GDP per capita for country i. A series of regressions using different estimation methods (fixed and random effects for country and for country and time, etc.) and data transformations (logarithm, standardized GDP per capita across countries, total industrial water use, per capita industrial water use, etc.) were performed. The results in general showed statistically insignificant estimates for the parameters, with R^2 being mostly below 0.2. This is, nevertheless, expected. As shown in the regressions for individual countries (Table 1), the GDP per capita corresponding to the turning point of industrial water use varies widely across countries. The coefficients of independent variables also differ, indicating that the slopes of industrial water use Kuznets curve vary according to country. As Eq (4) assumes a common turning point and a same slope of the Kuznets curve across countries, it cannot (and also should not) derive statistically significant estimates. This result suggests a need for caution in using panel data for EKC modeling in cross-country studies.

4. WHERE ARE THE POSITIONS OF DEVELOPING COUNTRIES ON THE INDUSTRIAL WATER USE KUZNETS CURVE?

While industrial water use in most developed countries has been stable or declined, most developing countries have seen a continued expansion in industrial water use in association with the industrialization and the population growth. A question that arises is how much more water will be needed in the industrial sector in developing countries before reaching the turning point. A comparison with the OECD countries may provide some insights.

Figure 3 shows industrial water use per capita and the GDP per capita in the OECD and non-OECD countries (predominantly developing countries) in 2000. An EKC shape of relationship can also be found between industrial water use and the GDP per capita across countries (in logarithmic form). At low income levels, the GDP per capita corresponds directly to the per capita water use. This correlation suggests that the economic growth in developing countries relies largely on material expansion, including the increasing use of water. The linkage tends to be loose above a certain level of income (e.g., log(GDP/per capita) > 3.5), implying that the income increase becomes less dependent on material expansion at the later stage of the economic development.

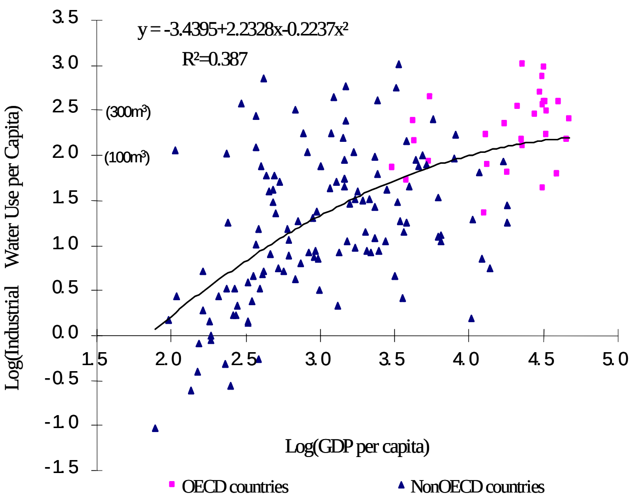

Figure 3. Industrial Water Use and GDP Per Capita by Country, 2000

It is also seen in Figure 3 that most developing countries have industrial water use below 100 m^3/capita, in contrast to most developed countries of around 300 m^3/capita. Hence, should developing countries follow the path of developed countries in industrialization, their industrial water use would have to increase substantially. Bearing in mind that industrial water use for the OECD countries shown in Figure 3 are the 'post-peak' volumes, the potential increase in developing countries would be even larger before reaching the turning point.

5. CONCLUDING REMARKS

This study investigated the Kuznets curve relationship between industrial water use and income in the OECD countries. The examination shows that industrial water use has experienced an increase, level-off and then decrease with income rises in most OECD countries. Statistical tests using multiple regression techniques supported the results derived from the visual observation. Therefore, the relationship between industrial water use and income can be displayed with the Kuznets curve.

The GDP per capita threshold corresponding to the turning point of industrial water use in the OECD countries ranges widely with a majority falling between USD10,000 and USD25,000.

The verification of the existence of the industrial water use Kuznets curve helps the prediction of the scale of future increase in industrial water use in developing countries. With the GDP growth and the economic structural upgrade, their industrial water use will eventually reach the peak. Nevertheless, a large gap is found between the current industrial water use and the projected peak industrial water use in developing countries. The results suggest an importance for developing countries to search for alternative ways of water use to reduce the demand for additional water in the process of industrialization.

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