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SCALE EFFECT VERSUS INDUCED POLICY RESPONSE IN THE ENVIRONMENTAL KUZNETS CURVE: THE CASE OF U.S. WATER POLLUTION

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The environmental Kuznets curve (EKC) could arise from the scale effect in abatement technology as emphasized by Andreoni and Levinson (2001) or from the induced policy response as suggested by Grossman and Krueger (1995). This paper incorporates these two contrary views into a model and quantitatively evaluates their relative importance in shaping the EKC of U.S. water pollution. Our main findings include: (a) some scale effect in abatement technology must exist, otherwise the turning point of the EKC will be unreasonably high; (b) the scale effect alone is not sufficient to explain the practical occurrence of the turning point of the EKC; and (c) the scale effect features critically in the induced policy response as well. (*JEL* H41, O40, Q20)

I. INTRODUCTION

Kuznets (1955) studied the relationship between income inequality and economic growth, showing that income inequality set against income per capita exhibits an inverted-U shape: increases in incomes will be associated with a deterioration in income inequality when incomes are low, but with an improvement in income inequality when incomes become high. This relationship is known as the "Kuznets curve." Starting with the seminal work of Grossman and Krueger (1993), many studies have found that pollution set against income per capita for various pollutants also exhibits an inverted-U shape, and so this relationship has been dubbed the "environmental Kuznets curve" (EKC).[1]

The existence of the EKC implies that economic growth may be a remedy for environmental problems because it will level off pollution and eventually bring about environmental improvements. Andreoni and Levinson (2001) provided a case for this possibility. They argued for increasing returns in pollution abatement technology (doubling the environmental efforts more than doubles the pollution abatement) and showed that the scale effect alone is sufficient to generate the EKC. By contrast, Grossman and Krueger (1995) emphasized that the eventual decline in pollution as income rises is not automatic or inevitable; instead, they suggested that "the strongest link between income and pollution in fact is via an induced policy response" (p. 372).

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1. For recent reviews on the EKC hypothesis, see Dasgupta et al. (2002), Copeland and Taylor (2004), Dinda (2004), Stern (2004), Yandle, Bjattarai, and Vijayaraghavan (2004), and Kijima, Nishide, and Ohyma (2010). Recently, several studies have focused on more advanced econometric methods of estimation. For example, Lee, Chiu, and Sun (2010) used the GMM approach; Wang (2011) and Paudel, Lin, and Pandit (2011) adopted nonparametric regressions to revisit the EKC hypothesis; and Lin and Liscow (2012) addressed the potential endogeneity of income in estimating the EKC.

ABBREVIATIONS

A&L: Andreoni and Levinson (2001)
BOD: Biochemical Oxygen Demand
CB: Census Bureau
COD: Chemical Oxygen Demand
EKC: Environmental Kuznets Curve
EPA: Environmental Protection Agency
GDP: Gross Domestic Product
GMM: Generalized Method of Moments
OECD: Organization for Economic Cooperation and Development
wtp: Willingness-to-Pay for Environmental Improvement

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In this paper, we incorporate these two contrary views into a model, allowing for the occurrence of the EKC via the scale effect in abatement technology as emphasized by Andreoni and Levinson (2001), and via the induced policy response as suggested by Grossman and Krueger (1995). Our main purpose is to quantitatively discern the relative importance of the scale effect versus the induced policy response in shaping the EKC. Water pollution in the United States will be our case study.[2]

Besides the main purpose stated above, we also address several related issues. Kristrom and Riera (1996) reviewed contingent valuation studies and evaluated the evidence on the income elasticity of people's willingness-to-pay for environmental improvement (wtp). They concluded that the value of this parameter is positive, but is consistently found to be less than 1. Later studies, including Aldy, Kramer, and Holmes (1999), Ready, Malzubris, and Senkane (2002), and Hokby and Soderqvist (2003), also confirmed this conclusion. However, Pearce and Palmer (2001) documented the Organization for Economic Cooperation and Development (OECD) public expenditures on pollution abatement and control and found that the income elasticity of these expenditures is close to 1.2. One may thus wonder if there is an inconsistency between Pearce and Palmer's "luxury good" finding and Kristrom and Riera's "normal good" finding. Kristrom and Riera (1996, 45) at the beginning of their paper remarked: "most economists would argue intuitively that environmental quality is a luxury good, [but] our results do not support this intuition." Pearce and Palmer (2001, 426) commented on Kristrom and Riera's finding: "If they are right, then the 'environment' is a normal good but not a luxury good, contradicting the usual intuition about the demand for environmental quality." In this paper we reconcile these two seemingly contradictory findings.

The importance of preferences in shaping the EKC has been emphasized in several papers.[3] By contrast, Andreoni and Levinson (2001) argued for increasing returns in pollution abatement and showed that the scale effect in technology alone is sufficient to generate the EKC. Andreoni and Levinson did not address the implications of increasing returns for environmental policy. We do that in this paper. As will be seen, technology as well as preferences may drive public environmental expenditures in our model as income grows. Nevertheless, we show that the scale effect features critically in the induced policy response.

Egli and Steger (2007) showed that the scale effect in technology is necessary for generating some practical turning point of the EKC in simulation. Their finding critically depends on the assumption that an individual's wtp is a constant term. As a result, the pollution turning down in their model must appeal to the feature of increasing returns to scale in abatement. Our model relaxes this restriction on preferences and thus the simulated pollution turning down can arise in our setting even in the absence of increasing returns to scale in abatement. Importantly, our quantitative evaluation is based on real-world data, while that of Egli and Steger (2007) is not.

The more recent evidence has shown that the inverted U-shaped relationship between pollution and income per capita is less robust than previously thought (see Stern 2004 for a critical review). Some papers, such as Stern and Common (2001) and Hill and Magnani (2002), have attacked the EKC issue from the viewpoint of the omitted-variable problem. The latter paper found empirically that income inequality is an important omitted variable. In this paper, we provide a policy-response channel through which income inequality will be related to environmental degradation.

The remainder of the paper is organized as follows. Section II introduces our model. Section III derives the equilibrium environmental policy resulting from the model. Section IV theoretically explores the link between income and pollution as income grows. Section V quantitatively evaluates the relative importance of the scale effect versus the induced policy response in shaping the EKC. Section VI concludes.

II. MODEL

Our model is built on Andreoni and Levinson (2001, hereafter A&L), but with two main modifications. First, instead of being a constant, we allow a person's wtp to positively depend on her own income. As noted in the "Introduction" section, the extant evidence shows that wtp is an increasing function of income. This dependence will play an important role in our analysis. Second, environmental effort to clean

2. As will be clear, our methodology can be applied to study other pollutants.

3. See Dinda (2004) for a review.

up pollution is assumed to be a private action in A&L. We replace the private action with collective action. This replacement will facilitate our analysis of the link between income and pollution via an induced policy response. Pearce and Palmer (2001) documented the OECD data on pollution abatement and control expenditures, showing that a large part of the environmental effort is channeled through collective action (as public expenditures directly or private expenditures indirectly via regulation).

Both preferences and technology are assumed to take specific functional forms. This will enable us to derive a closed-form solution, paving the way for the simulation study later.

Consider an economy in which the size of the population is normalized to unity so that the aggregate income of the economy is equal to its mean income. Each individual in the economy is characterized by an income. Individual i's income is denoted by $m_i \in (0, \infty)$ and her preferences are represented by the utility function:

$$U_i = c_i - \lambda_i P \tag{1}$$

where c_i is consumption (a private good), P is pollution (a public bad), and $\lambda_i > 0$ is the marginal disutility of pollution with $\lambda_i = \lambda(m_i)$, where $\lambda(.)$ is a common function. Note that λ_i represents individual i's wtp as $(\mathrm{d}c_i/\mathrm{d}P)_{U_i=\bar{U}} = \lambda_i$.

ASSUMPTION 1. $0 < \varepsilon_i < 1$ for all i's, where $\varepsilon_i \equiv (\mathrm{d}\lambda/\mathrm{d}m_i)(m_i/\lambda)$.

ε_i denotes the income elasticity of wtp. Kristrom and Riera (1996) reviewed and evaluated the evidence on the income elasticity of people's wtp. They concluded that the value of this parameter is positive, but is consistently found to be less than 1. Recent papers by Aldy, Kramer, and Holmes (1999), Ready, Malzubris, and Senkane (2002), and Hokby and Soderqvist (2003) have also confirmed this conclusion.[4]

As in A&L, pollution is a byproduct of consumption, but it can be abated through environmental effort. The pollution technology is represented by:

$$P = C - C^{\alpha} G^{\beta} \tag{2}$$

where C is the aggregate or mean consumption of the economy and G is the amount of income devoted to pollution abatement and control. Note that P consists of two components. The first term, C, denotes the gross pollution before abatement and is one-to-one related to consumption. The second term, $C^{\alpha}G^{\beta}$, represents the pollution abatement. If there were no environmental effort ($G = 0$), $P = C$ would hold according to Equation (2). In our model $s = G/M$, where M is the aggregate or mean income of the economy and s is the share of income devoted to pollution abatement and control. A main difference between our model and A&L's is that while s is privately chosen in A&L, it is collectively determined (say, by taxation or regulation) in our setting. The variable s represents the environmental policy of our economy.

ASSUMPTION 2. $0 < \alpha, \beta < 1$ and $\alpha + \beta \geq 1$.

The case where $\beta = 0$ is obviously uninteresting, while the case where $\alpha = 0$ leaves out the plausible possibility that the abatement productivity of G has to do with the existing level of pollution.[5] Most of our results hold under the weaker assumption that $\alpha, \beta \leq 1$. However, the assumption $\alpha, \beta < 1$ will enable us to rule out the "corner" policy $s = 0$ or 1. A&L argued for increasing returns or scale effects to abatement and provided some supporting evidence in the case of air pollutants. In our analysis, we take constant returns (i.e., $\alpha + \beta = 1$) as the benchmark, but allow for the impact of increasing returns (i.e., $\alpha + \beta > 1$).

Plassmann and Khanna (2006b) replaced C in Equation (2) by a function $P^G(C)$ with $\partial P^G/\partial C > 0$ and argued that the scale effect in the pollution abatement technology is neither sufficient nor necessary for the existence of the EKC. A key presumption to their argument is that abatement activities are to reduce the ambient concentration (the amount of pollution that a consumer is exposed to) rather than reduce emissions of pollution directly. If abatement activities are to reduce emissions directly, then the ambient concentration that a consumer is exposed to does not come from gross emissions (before abatement) but from net emissions (after abatement). Under such a situation, it can be shown that increasing returns to scale in

4. As long as the median-voter theorem is applicable (see later), Assumption 1 can be relaxed and need not hold for all individuals.

5. Pollution abatement, $C^{\alpha}G^{\beta}$, implies that the marginal abatement effect of G is conditional on the existing level of gross pollution C as long as $\alpha > 0$. The marginal abatement effect of G would be sparse if an environment were almost without any gross pollution.

abatement by themselves are still sufficient for the existence of the EKC.[6]

As admitted by Plassmann and Khanna (2006b), the practical relevance of their extending the A&L model is not definite. In the case of U.S. water pollution, which is the focus of this paper, it seems that the ambient concentration that a consumer is exposed to is net rather than gross emissions. Under environmental quality laws, which are part of the federal Clean Water Act for water quality, industrial and commercial businesses are prohibited from discharging wastewater into a river and are regulated to reduce unconventional pollutants, such as toxins and heavy metals, prior to discharging them into the municipal treatment plants instead. On the other hand, wastewater which is treated with chemical and biological processes to remove conventional pollutants like biochemical oxygen demand (BOD) by treatment plants is allowed to be discharged into rivers and streams (Fernandez 1997). Therefore, the wastewater treatment plants have become a major source of water pollution in U.S. rivers and streams (McConnell and Schwarz 1992).

III. ENVIRONMENTAL POLICY

A. Preliminary Analysis

Utilizing the constraint $c_i = (1 - s)m_i$ and Equations (1) and (2), one can derive $V_i(s)$, individual i's indirect preferences over policy s:

$$(3) \qquad V_i(s) = (1 - s)(m_i - \lambda_i M) + \lambda_i (1 - s)^\alpha s^\beta M^{\alpha+\beta}.$$

The preferred environmental policy of individual i is implicitly defined by the following equation:

$$(4) \quad (\partial V_i/\partial s) = (\partial c_i/\partial s) - \lambda_i(\partial P/\partial s) = 0$$

with

$$(4a) \quad (\partial c_i/\partial s) = -m_i$$

$$(4b) \quad (\partial P/\partial s) = -M - M^{\alpha+\beta}(1 - s)^{\alpha-1}s^{\beta-1}[\beta - (\alpha + \beta)s].$$

From Equation (4b), $\lim_{s\to 0}(\partial P/\partial s) = -\infty$ and $\lim_{s\to 1}(\partial P/\partial s) = \infty$ under Assumption 2. Thus, the preferred environmental policy of individual i, denoted by s_i, must satisfy $0 < s_i < 1$.

Using Equation (4b) yields:

$$(5) \quad (\partial^2 P/\partial s^2) = -M^{\alpha+\beta}(1 - s)^{\alpha-2}s^{\beta-2}[\alpha(\alpha - 1)s^2 + \beta(\beta - 1)(1 - s)^2 - 2\alpha\beta s(1 - s)].$$

The sign of Equation (5) is positive under Assumption 2, which implies that $P(\cdot)$ is strictly convex with respect to s and reaches its minimum at $\partial P/\partial s = 0$. Putting this result together with $\partial c_i/\partial s$ being a negative constant (see Equation (4a)), we see from Equation (4) that s_i will be located in the regime where $\partial P/\partial s < 0$ and that this s_i is unique. Finally, $\partial^2 P/\partial s^2 > 0$ implies that $\partial^2 V_i/\partial s^2 < 0$ and, therefore, the unique s_i that satisfies Equation (4) is the preferred environmental policy of individual i.

Let $f(s) \equiv (1 - s)^{\alpha-1}s^{\beta-1}[\beta - (\alpha + \beta)s]$ (see Equation (4b)). From Equation (4), we obtain:

$$(6) \quad s_i = f^{-1}[((1/\lambda_i)\cdot(m_i/M) - 1)M^{1-(\alpha+\beta)}]$$

where $f^{-1}(\cdot)$ is the inverse function of $f(\cdot)$. Utilizing Equation (6) gives:

$$(7) \quad (\partial s_i/\partial m_i) = [(1 - \varepsilon_i)/\lambda_i M^{\alpha+\beta}(\mathrm{d}f/\mathrm{d}s)]$$

whose sign is negative since $\varepsilon_i < 1$ under Assumption 1 and $\mathrm{d}f/\mathrm{d}s < 0$. Thus, given M (the mean income of the economy), the preferred share of income devoted to pollution abatement and control is strictly decreasing with respect to individual income: the higher the m_i, the lower the s_i. Assumption 1, $0 < \varepsilon_i < 1$, implies that the growth of willingness-to-pay will be less than the growth of personal income, even though willingness-to-pay is increasing in income. However, the growth of actual spending on environmental improvement will be equal to the growth of personal income if s remains constant as the consumer's income grows. The richer consumer will prefer a lower s_i because he is unwilling to continue to pay the same proportion of expenditure as he becomes richer.

Kahn and Matsusaka (1997) and Kahn (2002) studied the voting behavior in relation to environmental ballot propositions in California and concluded that being proenvironment does not mean being proenvironmental regulation. Kahn and Matsusaka (1997) showed that the fraction of votes cast in favor in a county is significantly decreasing with income for the high income

6. Assuming pollution in terms of concentrations, which increase monotonically with net emissions: $P = P^G(NetE)$, $NetE = C - C^\alpha E^\beta$ where E is private abatement, $NetE$ is net emissions after abatement, and $\partial P^G/\partial NetE$ is positive and finite. It can be checked that the inverse-U-shaped curve of the $NetE$-income relationship will exist following Theorem 1 of A&L.

voters. Later, Kahn (2002) also confirmed this conclusion that richer people do not exhibit greater support for environmental regulation.

B. Equilibrium Policy

Now suppose that the individuals in the economy vote over the environmental policy under the simple majority rule. Since the policy preferences of the individuals are single-peaked ($\partial^2 V_i/\partial s^2 < 0$) and since their preferred share of income devoted to pollution abatement is strictly decreasing with respect to income ($\partial s_i/\partial m_i < 0$), one can invoke the median-voter theorem. From Equation (6), the economy's environmental policy in the voting equilibrium is given by

(8) $s_m = f^{-1}[((1/\lambda_m)\cdot(m/M) - 1)M^{1-(\alpha+\beta)}]$

where m is the median income of the economy and $\lambda_m = \lambda(m)$.

According to Equation (8), three factors drive the economy's share of income devoted to pollution abatement and control (remember that $\mathrm{d}f/\mathrm{d}s < 0$):

1. Individual preferences (λ_m). Given m/M, an increase in the mean income of the economy will raise the median-income voter's wtp and hence result in a higher s_m.
2. Returns to scale of the abatement technology ($\alpha + \beta$). From the property of $f(s)$, the effect induced by preferences in (1) will be strengthened by increasing returns to abatement ($\alpha + \beta > 1$) if $m/M > \lambda_m$, but it will be weakened if $m/M < \lambda_m$.
3. Income inequality (m/M). The income distributions of almost all economies are found to be skewed to the right and hence $M > m$. The ratio m/M can be regarded as a measure of income inequality in the economy: the lower the ratio, the higher the income inequality. Equation (8) tells us that the higher the income inequality in the economy, all else equal, the higher will be the share of the economy's income devoted to pollution abatement.

C. Some Comparative Statics

To examine more precisely the impact of M on s_m, we let m be a function of M. From Equation (8), we then have:

(9)
$$\frac{\mathrm{d}s_m}{\mathrm{d}M} = \frac{-1}{\mathrm{d}f/\mathrm{d}s}\left\{\frac{1}{\lambda_m}\left[\frac{m}{M} - (1-\varepsilon_m)\frac{\mathrm{d}m}{\mathrm{d}M}\right] + \left(\frac{m}{\lambda_m M} - 1\right)[(\alpha+\beta) - 1]\right\}M^{-(\alpha+\beta)}$$

where ε_m is the median-income voter's income elasticity of wtp. Equation (9) allows for the impact of individual preferences, abatement technology, and income inequality simultaneously.

If the abatement technology exhibits constant returns to scale so that $\alpha + \beta = 1$ and the ratio m/M remains constant so that $\mathrm{d}m/\mathrm{d}M = m/M$, Equation (9) will be reduced to

(9) $(\mathrm{d}s_m/\mathrm{d}M) = [(-m)/\lambda_m M^2(\mathrm{d}f/\mathrm{d}s)]\varepsilon_m$

whose sign will always be positive. Equation (9a) sorts out the single impact of individual preferences for environmental quality (wtp) on the evolution of public expenditures on pollution abatement and control. It is clear from Equation (9a) that $\mathrm{d}s_m/\mathrm{d}M > 0$ as long as $\varepsilon_m > 0$. That is, the share of income devoted to pollution abatement and control will rise as income grows (the so-called luxury good), as long as the income elasticity of wtp is positive, and there is no need for the income elasticity of wtp to exceed 1 as thought by Kristrom and Riera (1996), Pearce and Palmer (2001), and others.

IV. INCOME AND POLLUTION

This section turns to explore the link between income and pollution. We only bring up questions and leave our answers to the next section.

Using Equation (2) yields:

(10) $$\frac{\mathrm{d}P}{\mathrm{d}M} = \frac{\partial P}{\partial M} + \frac{\partial P}{\partial s}\cdot\frac{\mathrm{d}s}{\mathrm{d}M}$$

with

(10a)
$$(\partial P/\partial M) = (1-s) - (\alpha+\beta)(1-s)^{\alpha}s^{\beta}M^{\alpha+\beta-1}$$

where $\partial P/\partial s$ and $\mathrm{d}s/\mathrm{d}M$ are given by Equations (4b) and (9), respectively. According to Equation (10), the effect of income on pollution can be decomposed into two components: the autonomous change represented by the first RHS term of Equation (10) and the induced policy response captured by the second RHS term of Equation (10). The so-called automatic change simply means that it is independent of the policy change. Since $\partial P/\partial s < 0$ in equilibrium, the induced policy response will contribute to the reduction in pollution if and only if $\mathrm{d}s/\mathrm{d}M > 0$. We consider the automatic change and the induced policy response in turn.

A. Autonomous Change

It is interesting to know what would happen if there were no induced policy response, i.e., $\mathrm{d}s/\mathrm{d}M = 0$ in Equation (10). Consider the benchmark technology with $\alpha + \beta = 1$. Then Equation (10) would be reduced to

(10b)

$$(\mathrm{d}P/\mathrm{d}M) = (\partial P/\partial M) = (1 - s) - (1 - s)^{\alpha} s^{\beta}$$

which implies that P is a linear, increasing function of M with a given s. This is obviously inconsistent with the EKC hypothesis. Grossman and Krueger's (1995) suggestion appears correct in this case, in the sense that there is no automatic decline in pollution as income rises.

However, with $\alpha + \beta > 1$, it can be readily seen from Equation (10a) that $\partial P/\partial M < 0$ will hold with a given s, as long as income M is sufficiently high. If doubling the environmental efforts can more than double the pollution abatement, pollution will decline eventually as an economy grows. Thus, the shape of the pollution–income relationship follows the EKC hypothesis even if there is no induced policy response. This is basically the result discovered by A&L, although we derive it in the context of collective rather than private environmental effort. Grossman and Krueger's (1995) suggestion appears incorrect in this case, in the sense that, as argued by A&L, the scale effect alone is sufficient to level off pollution.

To be sure, the autonomous change presents only a partial picture. In order to see the whole picture, we need to know the induced policy responses as well as autonomous changes. Grossman and Krueger (1995) suggested the important role of induced policy responses in the generation of the EKC. This leads us to study the link between income and pollution via the induced environmental policy response.

B. Induced Policy Response

Again, let us consider $\alpha + \beta = 1$ and $\alpha + \beta > 1$ separately.

If $\alpha + \beta = 1$, Equation (2) becomes:

$$P = [(1 - s) - (1 - s)^{\alpha} s^{1-\alpha}]M \tag{11}$$

It is clear from Equation (11) that the economy's pollution would increase proportionally to its income if there were no induced policy response (i.e., no change in s). We are interested in knowing in this case if the EKC hypothesis will hold once the induced policy response is taken into account.

If $\alpha + \beta > 1$, Equation (2) becomes:

$$P = (1 - s)M - (1 - s)^{\alpha} s^{\beta} M^{\alpha+\beta}. \tag{12}$$

We have shown that, even in the absence of an induced policy response, increasing returns to abatement alone is sufficient to level off pollution so that the pollution–income relationship will obey the EKC hypothesis. We are interested in knowing the relative importance of the scale effect versus the induced policy response in shaping the EKC.

C. Comparison with Plassmann and Khanna (2006a)

The change[7] in pollution with respect to income, $\mathrm{d}P/\mathrm{d}M$, is decomposed into the automatic change and the induced policy response according to Equation (10). This decomposition corresponds to the main purpose of our paper, that is, it quantitatively discerns the relative importance of the scale effect versus the induced policy response in shaping the EKC.

In a representative-agent framework, Plassmann and Khanna (2006a) considered a different decomposition:

$$\frac{\mathrm{d}P}{\mathrm{d}M} = \frac{\partial P}{\partial C} \cdot \frac{\mathrm{d}C}{\mathrm{d}M} + \frac{\partial P}{\partial E} \cdot \left(1 - \frac{\mathrm{d}C}{\mathrm{d}M}\right)$$

where E denotes spending part of the resources on the environmental effort, which is analogous to G in our model. This decomposition leads to

$$\frac{\mathrm{d}P}{\mathrm{d}M} \lesseqqgtr 0 \Leftrightarrow \frac{\mathrm{d}C}{\mathrm{d}M} \lesseqqgtr \frac{\partial P/\partial E}{\partial P/\partial E - \partial P/\partial C}$$

which in turn leads to Plassmann and Khanna's (2006a, 636) Lemma 1.

A necessary condition for obtaining a nonmonotonic equilibrium relationship between income and pollution is that one of the following conditions holds: (1) the pollution function $P(C, E)$ is nonhomogeneous; (2) the utility function $U(C, -P(C, E)) = V(C, E)$ is nonhomothetic.

This Lemma need not hold in our heterogeneous-agent framework, however.

Let $\alpha + \beta = 1$ in Equation (2) and $\lambda_i = 1$ for all i's in Equation (1), which implies that the pollution function in Equation (2) is homogeneous (since $\alpha + \beta = 1$), and that the utility function in Equation (1) is homothetic (since

7. See also Plassmann and Khanna (2006b), which is a direct comment on the A&L paper.

$\lambda_i = 1$ for all i's). With these restrictions, Equations (8) and (10) become:

$$s_m = f^{-1}(R-1) \tag{8a}$$

(10c)

$$\frac{\mathrm{d}P}{\mathrm{d}M}\Big|_{\alpha+\beta=1,\lambda=1} = (1-s_m) - (1-s_m)^{1-\beta}s_m^{\beta} - [1+(1-s_m)^{-\beta}s_m^{\beta-1}(\beta - s_m)]\frac{\mathrm{d}R}{\mathrm{d}M}\frac{M}{\mathrm{d}f/\mathrm{d}s}$$

where $R = m/M$, the median–mean income ratio. As long as a society's income inequality (measured by m/M in our model) keeps on worsening as income grows and so s_m gets higher and higher according to Equation (8a), it is possible that the sign of $\mathrm{d}P/\mathrm{d}M$ in Equation (10c) will turn from positive to negative as income increases. As a result, a nonmonotonic equilibrium relationship between income and pollution will arise, even though the pollution function is homogeneous *and* the utility function is homothetic.

The following example illustrates this possibility within our model with the restrictions that $\alpha + \beta = 1$ and that $\lambda_i = 1$ for all i's. Let $\beta = 0.383214$, which is in the range of our estimates for β in Section V. Now suppose that $R = 1 - 0.000008 * M$ so that the ratio m/M will keep worsening as income grows. Then from Equations (8a) and (10c), numerical calculations show that $\mathrm{d}P/\mathrm{d}M = 0$ occurs at per capita income \$14,302 (the corresponding $s_m = 0.438368$). It can be checked that both $\mathrm{d}P/\mathrm{d}M > 0$ and $\mathrm{d}P/\mathrm{d}M < 0$ will arise when M deviates from \$14,302.[8]

A subtle difference between our model and Plassmann and Khanna (2006a) is also worth noting. Let $\lambda_i = 1$ for all i's so that the utility function is homothetic. Then Equation (8) will become

$$s_m = f^{-1}[((m/M) - 1)M^{1-(\alpha+\beta)}]. \tag{8b}$$

The value of $m/M - 1$ is negative for most societies since positively skewed income distributions are most often observed in the real world. This suggests that a society's choice of s will be dependent upon M as long as the society's pollution technology is nonhomogeneous ($\alpha + \beta \neq 1$). By contrast, for a representative-agent framework, $m/M = 1$ must hold and so Equation (8b) will reduce to:

$$s = f^{-1}(0). \tag{8c}$$

Since $f(s) = (1-s)^{\alpha-1}s^{\beta-1}[\beta - (\alpha+\beta)s]$, Equation (8c) then implies that $s = \beta/(\alpha+\beta)$, which is a constant. This suggests that a society's choice of s will be independent of M even if the society's pollution technology is nonhomogeneous ($\alpha + \beta \neq 1$).

As will be shown later, our results for the U.S. case of water pollution are not sensitive to the realistic change in the inequality measure m/M. Thus, as far as this paper is concerned, the subtle difference above may be more important.

V. QUANTITATIVE EVALUATION OF SCALE EFFECT VERSUS INDUCED POLICY RESPONSE

In this section, we apply our model to the case of U.S. water pollution, quantitatively evaluating the relative importance of the scale effect as emphasized by Andreoni and Levinson (2001) versus the induced policy response as suggested by Grossman and Krueger (1995) in shaping the EKC.

A. Methodology

Our evaluation is on the basis of Equation (10), in which the first RHS term represents the automatic change, while the second RHS term represents the induced policy response. As is clear from Equation (10), we need to specify or estimate several key parameters for this evaluation. Our methodology includes the following two steps:

Step 1. Specifying a value for ε_m (the median-income voter's income elasticity of wtp).

To estimate λ_m in Equation (8), we let $\lambda_m = \lambda(m) = a \cdot m^{\varepsilon_m}$, where a is a scalar. Note that $\varepsilon_m = (\mathrm{d}\lambda/\mathrm{d}m)(m/\lambda)$ by this specification. The U.S. public's income elasticity of willingness to pay for quality water is between 0.1 to 0.16 according to Jordan and Elnagheeb (1993), between 0.2 to 0.3 according to Carson and Mitchell (1993), but equal to 0.959 according to Carson et al. (1992). The last study examined the case of the Exxon Valdez oil spill. Its estimate of 0.959 seems to be an outlier when compared to the other two studies. Nevertheless, in our quantitative evaluation we use it as the upper bound and pick four alternative values for ε_m: 0.1, 0.2, 0.3, and 0.959. The scalar a that appears in λ_m will be estimated using real-world data.

8. Suppose instead that $R = 1 - 0.000001 * M$, then $\mathrm{d}P/\mathrm{d}M = 0$ occurs at per capita income \$114,419.

Step 2. A process of trials and errors for choosing a value for $\alpha+\beta$ that yields a turning point close to the observed one and selects a, α, and β at every iteration.

Given ε_m, we choose a value for $\alpha+\beta$. The selection criterion for the "right" choice will be spelt out later. Note that, in order to evaluate the evolution of the pollution level P according to Equation (2) and of the policy response s_m according to Equation (8) quantitatively, we need to know the value of α and of β, respectively as well as that of $\alpha+\beta$. We first explain how we estimate β (or, equivalently, α) after a choice of $\alpha+\beta$ has been made.

Let

$$s(t) = s_m(t) + e(t)$$

where $s(t)$ represents the actual share of income devoted to pollution abatement and control at time t, $s_m(t)$ is the share of income devoted to pollution abatement and control at time t predicted by our theoretical model according to Equation (8), and $e(t)$ is the random error that characterizes the discrepancy between the actual $s(t)$ and the predicted $s_m(t)$. Our method is to select parameters a and β to minimize $\sum_t [e(t)]^2$, which is known as the least-squares criterion often used to fit regressions in econometrics. More specifically, by substituting $\lambda_m = a{\cdot}m^{\varepsilon_m}$ in Equation (8) where a value is specified for ε_m from Step 1, choosing a value for $\alpha+\beta$ where the choice is explained later, and utilizing the real-world data for M and m/M, we can calculate the theoretical prediction $s_m(t)$ according to Equation (8) with $f(s_m) = (1-s_m)^{\alpha-1}s_m^{\beta-1}[\beta-(\alpha+\beta)s_m]$. Note that the calculated $s_m(t)$ depends on the parameters a and β. Finally, we select the parameter values for a and β such that the theoretical prediction series $s_m(t)$ fit the observed series $s(t)$ best, in the sense that the sum of the squared error terms $\sum_t [e(t)]^2$ is minimized.[9]

Data on M (per capita gross domestic product [GDP] in constant 1985 dollars) are calculated from EconStats (http:/www.econstats.com), while data on m/M (the ratio of median to mean income) are obtained from the U.S. Census Bureau (CB; 1991, 2005). The U.S. Environmental Protection Agency (EPA; 1990) reported actual water pollution abatement and control expenditures from 1972 to 1986 and projected future expenditures from 1987 to 2000. We use the EPA data to calculate s_m in this study.[10] Table 1 lists the data we use in our methodology.

For any combination of ε_m and $\alpha+\beta$, we have obtained the corresponding estimated a, α, and β. Substituting in the real-world data for income M, we can simulate the evolution of s_m according to Equation (8) and then the evolution of P according to Equation (2). The purpose of the simulations is to pick the "right" value for $\alpha+\beta$. Unless stated otherwise, we let $m/M = 0.75$ in our simulation as a benchmark. We examine the sensitivity of varying values for m/M later on. Let us explain the procedure in more detail.

Our methodology starts by specifying four different values for ε_m: 0.1, 0.2, 0.3, and 0.959. After choosing a value for $\alpha+\beta$, we then estimate a, α, and β. However, for each value of ε_m, there are many possible values of $\alpha+\beta$ that could be chosen. How do we differentiate between them? Grossman and Krueger (1995) studied the EKC hypothesis for river pollution in the United States and found that the turning point incomes for various water quality indicators were around a per capita GDP of \$7,600 to \$7,900.[11] We use this as a criterion to differentiate between various values of $\alpha+\beta$. More precisely, given any combination of ε_m and $\alpha+\beta$ and the corresponding estimated a,

9. Assumptions 1 and 2 imply that $1 > \beta > 0$ and $a > 0$. We utilize a solution procedure called "Minimize" in the software Mathematica to solve the minimization problem. This procedure allows for the imposition of constraints in the problem.

10. GDP data are obtained from EconStats (http:/www.econstats.com). The U.S. CB reported actual water pollution abatement and control expenditures from 1972 to 1994; see Vogan (1996). The agency renewed its data collection for the year 1999, but there were some changes in the way the data were collected. While the EPA data include private expenditures in both the household and business sectors, the CB data leave out private expenditures in the household sector. A disadvantage of the EPA data is that expenditures from 1987 to 2000 are projected rather than actual. However, because the questionnaire used by the CB to collect data asked corporate or government officials how capital expenditures compared with what they would have been in the absence of environmental regulation, there are some potential problems with the CB data; see Jaffe et al. (1995) for the detail.

11. This is a rough summary. Turning point incomes for some water quality indicators will be lower while others will be higher; see Grossman and Krueger (1995) for the detail. Our choice of the range between per capita GDP of \$7,600 and \$7,900 is based on the turning point for BOD being a per capita GDP of \$7,623 and that for chemical oxygen demand (COD) being a per capita GDP of \$7,853. Other empirical studies such as Cole (2004) and Paudel, Zapata, and Susanto (2005) also support the EKC hypothesis in the case of water pollution and the turning point incomes that they found are more or less compatible with those in Grossman and Krueger (1995).

TABLE 1
Data on Per Capita GDP (M), Ratio of Median to Mean Income (m/M), and Share of Income Devoted to Pollution Abatement (s_m)

Year	M	m/M	s_m
1972	13,632.47	0.88074	0.003389
1973	14,280.12	0.884651	0.003713
1974	14,079.12	0.877034	0.004366
1975	13,916.18	0.882482	0.004924
1976	14,514.58	0.886646	0.005384
1977	15,032.84	0.887689	0.005729
1978	15,703.21	0.877994	0.005899
1979	16,021.27	0.877708	0.006232
1980	15,800.65	0.876914	0.006728
1981	16,038.27	0.86842	0.007035
1982	15,578.34	0.855494	0.007608
1983	16,134.9	0.856159	0.007702
1984	17,144.11	0.851264	0.007553
1985	17,695	0.841881	0.007683
1986	18,142.01	0.843469	0.007924
1987	18,588.29	0.839646	0.008135
1988	19,181.34	0.833795	0.008012
1989	19,673.45	0.826676	0.008094
1990	19,818.52	0.800551	0.008306
1991	19,524.33	0.79442	0.008717
1992	19,907.16	0.788774	0.008768
1993	20,175.37	0.754104	0.008843
1994	20,733.4	0.748012	0.008791
1995	21,002.61	0.758289	0.008871
1996	21,527.75	0.753178	0.00882
1997	22,228.9	0.744687	0.008684
1998	22,228.9	0.749879	0.008576
1999	23,635.38	0.743482	0.008427
2000	24,231.54	0.734926	0.008317

Sources: Data on M are obtained from EconStats (http:/www.econstats.com) and data on m/M from the U.S. Census Bureau (1991, 2005). Data on s_m are calculated from the U.S. Environmental Protection Agency (1990).

α, and β, we examine the resulting evolution of P simulated according to Equation (2). We only accept those values of $\alpha + \beta$ such that the resulting turning point income (i.e., the income that satisfies $\mathrm{d}P/\mathrm{d}M = 0$ in Equation (10)) is simulated to be around a per capita GDP \$7,600 to \$7,900.[12] The way for us to pick the right value for $\alpha + \beta$ is through trial and error. For example, if $\alpha + \beta = 1.1$ leads to a turning point income that is above \$8,000 while $\alpha + \beta = 1.3$ leads to a turning point income that is below \$7,000, then we will try $\alpha + \beta = 1.2$.

B. Results

By employing the methodology described above, we detect four scenarios that meet the criterion that the turning point income is around a per capita GDP of \$7,600 to \$7,900:[13]

Scenario 1: $\varepsilon_m = 0.1$, $\alpha + \beta = 1.3155$, $a = 0.003589$, $\beta = 0.625047$, turning point income $=$ \$7,781, and $s_m = 0.003567$ at the turning point;

Scenario 2: $\varepsilon_m = 0.2$, $\alpha + \beta = 1.305$, $a = 0.001383$, $\beta = 0.595763$, turning point income $=$ \$7,792, and $s_m = 0.003054$ at the turning point;

Scenario 3: $\varepsilon_m = 0.3$, $\alpha + \beta = 1.294$, $a = 0.000538$, $\beta = 0.566745$, turning point income $=$ \$7,764, and $s_m = 0.002654$ at the turning point;

Scenario 4: $\varepsilon_m = 0.959$, $\alpha + \beta = 1.205$, $a = 0.000001374$, $\beta = 0.383214$, turning point

12. For any combination of ε_m and $\alpha + \beta$, there will be a corresponding estimated a and β. The simulated $\mathrm{d}P/\mathrm{d}M$ is based on these ε_m, $\alpha + \beta$, a, and β.

13. Of course, other scenarios that deviate slightly from these four scenarios may still satisfy our turning-point criterion. The qualitative results of these "near" scenarios remain the same as those of our four scenarios.

income = \$7,771, and $s_m = 0.001489$ at the turning point.

Several features of these scenarios are worth noting. First, the resulting values for $\alpha + \beta$ show that there exist scale effects in abatement technology. This finding is consistent with evidence of scale economies in water pollution abatement in the United States reported by Fraas and Munley (1984) and McConnell and Schwarz (1992).[14] It is also consistent with the case in Canada reported by Renzetti (1999), who found that the scale economies for the sewage treatment equal 1.364. Secondly, the estimated s_m's that correspond to the turning points are all smaller than the actual s_m (0.0034) in the year 1972. This is reasonable as the per capita GDP for 1972 is \$13,632, while the per capita GDP at the turning point is \$7,750. Thirdly, there exists some substitution between ε_m and $\alpha + \beta$: as the value of ε_m increases, the corresponding value of $\alpha + \beta$ decreases. However, it is worth noting that a substantial increase in ε_m (from 0.1 to 0.959) only brings about a small reduction in $\alpha + \beta$ (from 1.3155 to 1.205).

Sensitivity of $\alpha + \beta$ *to Turning Point Income.* In the results reported above, we pick the "right" value for $\alpha + \beta$ on the basis of Grossman and Krueger's (1995) point estimates, which are around a per capita GDP of \$7,600–\$7,900. Below we examine the sensitivity of the value of $\alpha + \beta$ with respect to turning point income.

Per capita GDP from \$7,600 to \$7,900 were the point estimations for the water pollutants, BOD and COD. Grossman and Krueger also reported that the standard errors for the point estimations were around \$2,200–\$3,300. Thus, the 90% confidence intervals approximately ranged from \$2,100 to \$13,000. Given ε_m =0.2 and 0.959, we derive the corresponding values of $\alpha + \beta$ based on Grossman and Krueger's confidence intervals. Table 2 reports the results. It is not surprising to find that the range for the values of $\alpha + \beta$ becomes wider than before and, all else equal, a lower (higher) turning point income requires a higher (lower) value of $\alpha + \beta$ to sustain it. However, the changes are not large: the new range [1.165, 1.4370] is not very difficult from the old range [1.205, 1.305]. Importantly, note that all of them display scale effects in abatement technology, that is, $\alpha + \beta > 1$. Note also that the estimated s_m's that correspond to the lower-limit turning points are all significantly smaller than the actual s_m (0.0034) in the year 1972. This is reasonable since the per capita GDP for 1972 is \$13,632, while the per capita GDP at the lower-limit turning points are all considerably lower.

Recently, empirical research on the EKC for water pollution has focused on adopting a more advanced estimating approach, new pollution data, or new pollution indicators to estimate the relationship between pollution indexes and per capita income.[15] Table 3 summarizes these studies, showing that there is a broader range of the turning point income of the EKC compared to the Grossman and Krueger estimates. We pick \$4253, \$35,273, and \$38,221, which are extreme values in Table 3, as turning point incomes for further sensitivity analysis.

Table 4 reports the results. The most important thing to note is that all of them display scale effects in abatement technology, although the effects become much smaller in some cases. We conclude that scale effects in abatement technology are still present for the occurrence of the EKC, even if the turning point incomes are estimated to be much higher than those in Grossman and Krueger (1995).

C. Sensitivity to Distributional Conflict

In our simulation, we let $m/M = 0.75$ for simplicity. We now examine the sensitivity of

14. Fraas and Munley (1984) examined the cost of control for conventional pollution at municipal wastewater treatment plants which only maintain BOD effluent concentration equal to the mandatory level required by the laws. They found a significant decline in the marginal cost with the increasing flow size of treatment plants. McConnell and Schwarz (1992) allowed effluent concentrations to be endogenously determined and estimated the cost of BOD removal at municipal wastewater treatment plants. They showed that the marginal cost of BOD removal decreases as the plant size (measured by millions of gallons per day) becomes larger given the same effluent concentrations. The main operating costs for wastewater treatments come from energy, chemical consumption, and manpower (Fraquelli and Giandrone 2003). Balmer and Mattsson (1994) showed that the costs of manpower and electricity as well as total operating costs on a per capita basis decrease with increasing wastewater treatment plant size.

15. The water pollution estimated by List and Mchone (2000) reflects the percentage of river impaired and the percentage of lake impaired in the United States. Specifying the watershed level data for the state of Louisiana, Paudel, Zapata, and Susanto (2005) supported the EKC findings in the United States. Lee, Chiu, and Sun (2010) used a GMM approach to revisit the EKC hypothesis for water pollution, BOD. Lin and Liscow (2012) addressed the potential endogeneity of income in estimating the EKC, and Paudel, Lin, and Pandit (2011) adopted semiparametric and nonparametric regressions which address the inclusion of continuous and discrete variables to estimate the EKC for several types of pollutants.

TABLE 2
Range of $\alpha + \beta$ within 90% Confidence Intervals of Turning Point Income Estimated by Grossman and Krueger (1995)

	BOD[a] \$7,623(3,307)		COD[b] \$7,853(2,235)	
Income Elasticity of WTP	**Lower limit \$2,166**	**Upper limit \$13,079**	**Lower limit \$4,165**	**Upper limit \$11,540**
$\varepsilon_m = 0.2$	$\alpha + \beta = 1.43705$ $a = 0.00031336$ $\beta = 0.530873$ M^* =\$2,026 $s_m = 0.00044528$	$\alpha + \beta = 1.25865$ $a = 0.00231984$ $\beta = 0.61773$ M^* =\$13,392 $s_m = 0.0060883$	$\alpha + \beta = 1.365$ $a = 0.000704907$ $\beta = 0.566496$ M^* =\$4,106 $s_m = 0.00126495$	$\alpha + \beta = 1.2685$ $a = 0.00207947$ $\beta = 0.613134$ M^* =\$11,886 $s_m = 0.00525415$
$\varepsilon_m = 0.959$	$\alpha + \beta = 1.309$ $a = 4.57 \times 10^{-7}$ $\beta = 0.33716917$ M^* =\$2,111 $s_m = 0.000123$	$\alpha + \beta = 1.165$ $a = 2.08 \times 10^{-6}$ $\beta = 0.3990836$ M^* =\$12,945 $s_m = 0.0038873$	$\alpha + \beta = 1.255$ $a = 8.11 \times 10^{-7}$ $\beta = 0.36262$ M^* =\$4,182 $s_m = 0.000451156$	$\alpha + \beta = 1.174$ $a = 1.9 \times 10^{-6}$ $\beta = 0.395661$ M^* =\$11,536 $s_m = 0.00313315$

Note: M^* denotes the turning point income.
[a]The point estimate for the turning point income of water pollution indicator BOD is \$7,623 and the standard error of estimate is \$3,307. The 90% confidence interval of turning point income ranges between \$2,166 and \$13,079.
[b]The point estimate for the turning point income of the water pollution indicator COD is \$7,853 and the standard error of estimate is \$2,235. The 90% confidence interval of turning point income ranges between \$4,165 and \$11,540.

TABLE 3
Turning Point Income of the EKC for Water Pollution for Recent Empirical Research

Literature	The Estimated Turning Point Income
List and Mchone (2000)	\$14,044–\$25,336
Paudel, Zapata, and Susanto (2005)	\$6,636–\$12,993
Lee, Chiu, and Sun (2010)	\$13,956 for America, \$38,221 for Europe
Lin and Liscow (2012)	\$4,253–\$12,861
Paudel, Lin, and Pandit (2011)	\$11,424–\$35,273

varying values for m/M. From Table 1, we see that $m/M = 0.88$ in 1972, but that it declines all the way to $m/M = 0.73$ in the year 2000. To check the sensitivity of our previous evaluation, we choose three different values for m/M: 0.72, 0.75, and 0.9. The same criterion as before is employed to pick the right value for $\alpha +\ \beta$. Table 4 reports our findings, which show that: (a) when $\varepsilon_m = 0.2$, increasing m/M from 0.72 to 0.9 will enhance the value of $\alpha + \beta$ from 1.301 to 1.323, and (b) when $\varepsilon_m = 0.959$, increasing m/M from 0.72 to 0.9 will enhance the value of $\alpha + \beta$ from 1.205 to 1.2055. The sensitivity is somewhat higher when the value of ε_m is smaller. However, the values of $\alpha + \beta$ remain around 1.3 when $\varepsilon_m = 0.2$, while they remain around 1.2 when $\varepsilon_m = 0.959$. Overall, our results are not sensitive to the realistic change in m/M. In light of this finding, we shall focus on preference factor ε_m and abatement technology $\alpha + \beta$ (with m/M fixed at 0.75) from now on.

In what follows we ask two questions. First, what would happen to the turning point of the EKC if there were no scale effect? Second, what would happen to the turning point of the EKC if there were no induced policy response? Answering these two questions will allow us to assess the relative importance of the scale effect versus the induced policy response in shaping the turning point of the EKC in the case of U.S. water pollution. To save space, we only report our findings based on Scenarios 2 and 4. The results from Scenarios 1 and 3 are close to those from Scenario 2.

D. What Happens in the Absence of the Scale Effect?

In the absence of the scale effect, $\alpha + \beta = 1$. This exercise is contrary to what we have found and is also inconsistent with the extant evidence. However, it will enable us to see more clearly the role played by the scale effect in the EKC hypothesis.

Scenario 2: The turning point income equals \$7,792. If $\alpha + \beta = 1$ instead, then the turning point income becomes \$0.34 $\times 10^{12}$.

Scenario 4: The turning point income equals \$7,771. If $\alpha + \beta = 1$ instead, then the turning point income becomes \$629,290.

TABLE 4
Sensitivity of Varying the Turning Point Income

Literature	$\varepsilon_m = 0.2$	$\varepsilon_m = 0.959$
Lin and Liscow (2012) $4,253	$\alpha+\beta = 1.362$ $a = 0.00072886$ $\beta = 0.567861114$ $M^* =\$4,232$ $s_m = 0.001320861$	$\alpha+\beta = 1.253$ $a = 0.0000008270364668$ $\beta = 0.362517928$ $M^* =\$4,241.115502$ $s_m = 0.000470631$
Grossman and Krueger (1995) $7,625~$7,858	$\alpha+\beta = 1.305$ $a = 0.001383$ $\beta = 0.595763$ $M^* =\$7,792$ $s_m = 0.003054$	$\alpha+\beta = 1.205$ $a = 0.000001374$ $\beta = 0.383213773$ $M^* =\$7,771$ $s_m = 0.001489257$
Paudel, Lin, and Pandit (2011) $35,273	$\alpha+\beta = 1.1855$ $a = 0.005177$ $\beta = 0.651229$ $M^* =\$35,832$ $s_m = 0.018544$	$\alpha+\beta = 1.085$ $a =$ 0.00000472785507191509 $\beta = 0.427157733$ $M^* =\$35,932$ $s_m = 0.025999974$
Paudel, Lin, and Pandit (2011) $38,221	$\alpha+\beta = 1.182$ $a = 0.005348$ $\beta = 0.651176$ $M^* =\$37,746.14$ $s_m = 0.019472$	$\alpha+\beta = 1.08$ $a =$ 0.00000492050918600713 $\beta = 0.424585991$ $M^* =\$38,085$ $s_m = 0.028732183$

Note: M^* denotes the turning point income.

TABLE 5
Sensitivity of Varying Values for m/M

Income Inequality	$\varepsilon_m = 0.2$	$\varepsilon_m = 0.959$
$m/M = 0.72$	$\alpha+\beta = 1.301$ $a = 0.001447$ $\beta = 0.597688$ $M^* = 7,779$ $s_m = 0.003317$	$\alpha+\beta = 1.205$ $a = 0.000001374$ $\beta = 0.383213773$ $M^* = 7,762$ $s_m = 0.001490148$
$m/M = 0.75$	$\alpha+\beta = 1.305$ $a = 0.001383$ $\beta = 0.595763$ $M^* = 7,792$ $s_m = 0.003054$	$\alpha+\beta = 1.205$ $a = 0.000001374$ $\beta = 0.383213773$ $M^* = 7,771$ $s_m = 0.001489257$
$m/M = 0.9$	$\alpha+\beta = 1.323$ $a = 0.00113$ $\beta = 0.587052$ $M^* = 7,766$ $s_m = 0.002103$	$\alpha+\beta = 1.2055$ $a = 0.000001366$ $\beta = 0.383005228$ $M^* = 7,760$ $s_m = 0.001467547$

Note: M^* denotes the turning point income.

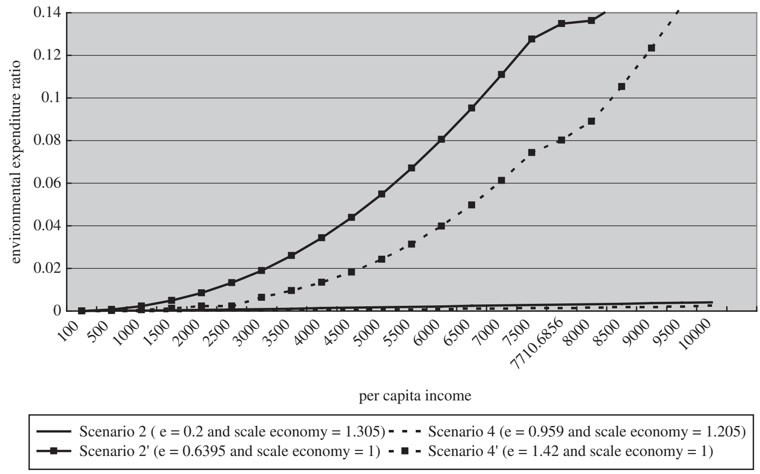
The turning point incomes under $\alpha+\beta=1$ in both scenarios are too high relative to the actual turning point. We conclude that some scale effect in abatement technology must exist, otherwise the turning point is unreasonably high.

We can see the importance of the scale effect from a different angle. Figure 1 plots simulated s_m for per capita GDP ranging between $100 and $10,000 for the "realistic" Scenarios 2 and 4 against the corresponding "unrealistic" Scenarios 2′ and 4′, in which the only modification is that the scale effect is assumed away so that $\alpha+\beta=1$ is imposed. Figure 1 clearly shows that the required s_m would become unreasonably high if the scale effect were to be absent.

E. What Happens in the Absence of the Induced Policy Response?

A&L argued that the scale effect in the pollution-abatement technology is sufficient for

FIGURE 1
Simulation of s_m for the Scenarios with the Same Turning Point Income



the existence of the EKC. We examine this argument for the practical occurrence of the EKC.

Scenario 2: The turning point income equals \$7,792 and the corresponding $s_m = 0.003054$. If we exogenously fix s_m at 0.003 and only consider the autonomous change due to the scale effect, then the turning point income will become \$35,293.

Scenario 4: The turning point income equals \$7,771 and the corresponding $s_m = 0.001489$. If we exogenously fix s_m at 0.0015 and only consider the autonomous change due to the scale effect, then the turning point income would become \$76,420.

Although the turning point incomes in the absence of the induced policy response are lower than those in the absence of the scale effect, they are still very high relative to the actual turning point. We conclude that the scale effect alone is not sufficient to explain the practical occurrence of the turning point of the EKC.

F. Preferences Versus Abatement Technology in the Induced Policy Response

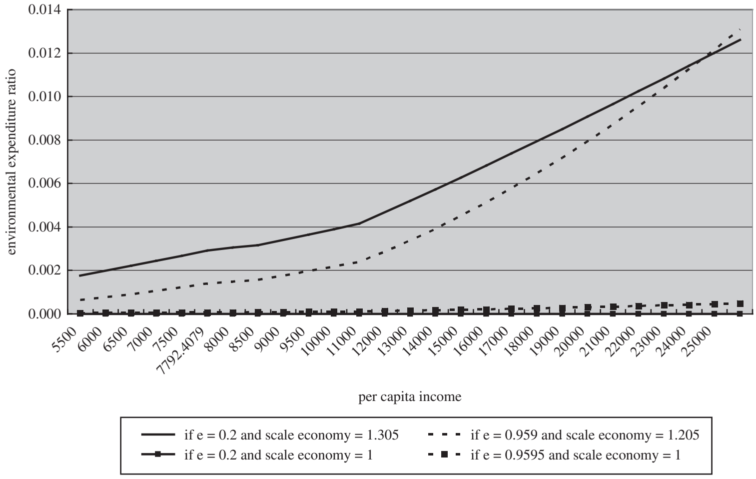
Overall, we have found that both the scale effect and the induced policy response contribute to the practical occurrence of the EKC in the case of U.S. water pollution. The last question we would like to explore is: What is the relative importance of preference factor ε_m versus abatement technology $\alpha + \beta$ in explaining the evolution of the induced policy response s_m according to Equation (8)?

Figure 2 plots the simulated s_m by varying ε_m and $\alpha + \beta$ for incomes ranging between \$5,000 and \$25,000. Our simulated s_m include four cases: (a) $\alpha + \beta = 1.305$ and $\varepsilon_m = 0.2$ (Scenario 2, which is represented by the solid curve), (b) $\alpha + \beta = 1$ and $\varepsilon_m = 0.2$ (what happens if $\alpha + \beta = 1.305$ in Scenario 2 is replaced by $\alpha + \beta = 1$, which is represented by the solid curve with the square-shaped point), (c) $\alpha + \beta = 1.205$ and $\varepsilon_m = 0.959$ (Scenario 4, which is represented by the dotted curve), and (d) $\alpha + \beta = 1$ and $\varepsilon_m = 0.959$ (what happens if $\alpha + \beta = 1.205$ in Scenario 4 is replaced by $\alpha + \beta = 1$, which is represented by the dotted curve with the square-shaped point). The figure clearly shows that restricting $\alpha + \beta = 1$ would dramatically reduce the value s_m compared to the cases where $\alpha + \beta > 1$, suggesting that the scale effect in abatement technology also features critically in the evolution of the induced policy response. To the best of our knowledge, this point seems to have been neglected in the extant literature.

G. Implications of Our Findings

Our main finding for explaining the occurrence of the EKC is that the scale effect in abatement technology features critically for driving the pollution turning down. We also find that the technology's impact on driving the pollution

FIGURE 2
Impact of Preference and Scale Effect on s_m



turning down takes place through two channels: (1) the autonomous change, and (2) the induced policy response. The turning point would likely occur at a much higher income level compared to the actual turning point income level if the scale effect in abatement technology were absent.

There are two possible implications for our findings. First, the pollution will start to decrease far later if an economy only relies on preferences to drive the induced policy. By contrast, economic growth will accelerate the concurrence with a remedy for the environmental problem if increasing returns in pollution abatement technology commonly apply. We have shown in Section V.B that there are scale economies in water pollution abatement in the United States and Canada. A&L have also shown that the average cost of abating air pollutants, such as SO_2, NO_X, and particulates, decrease with the level on abatement for the United States. These technologies were developed in the industrial countries over the past 50 years for the abatement of air pollution, and the past 150 years for the abatement of water pollution (Anderson 2001). That might explain why the industrial countries are experiencing a remedy for environmental problems with economic growth.

Second, there might be a possibility that the pollution starts to decrease at a lower income level for developing than for developed countries. Anderson (2001) used a dynamic model to simulate the relationship between the emission peak and the timing of adopting the advanced abatement technology for the developing countries. He found that the emission peak will occur earlier relative to the experience of industrial countries if developing countries could adopt those well-developed technologies at an earlier stage of development. There is some evidence that the advanced abatement technology has been diffused to developing countries. For instance, James and Murty (1996), Pandey (1998), and Goldar, Misra, and Mukherji (2001) all provided evidence of scale economies in abating water pollutants (BOD) in India. Zhang and Folmer (1998) showed that the marginal cost of abatement for air pollutants (CO_2,) has been significantly reduced with increasing electronic plant size. Overall, our paper has demonstrated the critical importance of the scale effect in abatement technology for the EKC, and so it seems reasonable to support Anderson's (2001) argument that the developing countries might have the emission peak earlier instead of repeating the environmental experiences of the industrial countries.

VI. CONCLUSION

The EKC could arise from the scale effect in abatement technology as emphasized by Andreoni and Levinson (2001) or from the induced policy response as suggested by

Grossman and Krueger (1995). In this paper, we incorporate these two contrary views into a model and quantitatively evaluate their relative importance in shaping the EKC of U.S. water pollution. Our main findings include: (a) some scale effect in abatement technology must exist, otherwise the turning point of the EKC will be unreasonably high; (b) the scale effect alone is not sufficient to explain the practical occurrence of the turning point of the EKC; and (c) the scale effect features critically in the induced policy response as well.

Overall, we have found that the scale effect in abatement technology stands out significantly in shaping the EKC in the case of U.S. water pollution. We hope that our paper contributes to a better understanding with regard to the scale effect of abatement technology in shaping the EKC.

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