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Specifying the EKC: Downstream Dependence in Water Pollution

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Abstract

The present study provides a utility maximizing theoretical framework motivating the EKC model. Theoretical parameters are linked directly to the typical empirical parameters of the reduced form empirical EKC model. Linking the theory to the typical empirically estimated parameters is relevant for devising policy and future EKC studies.

Keywords

Environmental Kuznets Curve, Downstream Dependence, Water Pollution

1. Introduction

The environmental Kuznets curve (EKC) describes the relationship between income per capita and environmental degradation as an inverted *U*-shape. At initial stages of economic development and low income per capita, environmental degradation increases with income because increased production leads to pollution. Eventually, the environmental problems are redressed as demand for environmental quality increases with rising income.

Since the initial EKC study by [1], a number empirical EKC studies have been published [2]-[9]. Theoretical EKC models that have been developed to help motivate the EKC have included infinitely-lived agent models ([10] [11]) and overlapping generation models ([12]). [13] develop the Green Solow Model, an extension of the Solow model including a resource constraint.

[14] approach the EKC from a consumer standpoint and assumes increasing returns to pollution abatement. These authors derive conditions for a turning point or the point at which pollution degradation is maximized. The present study provides a utility maximizing theoretical framework motivating the EKC model. Theoretical parameters are linked directly to the typical empirical parameters of the reduced form empirical EKC model. Linking theoretical parameters to the typical empirically estimated parameters is relevant for devising policy and future EKC studies.

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2. Theory

Consider agent 1 in the upstream country (*U*) and agent 2 in the downstream country (*D*). The utility of agent 1 is a general function of their consumption and pollution,

$$U_U = U\left(C_U, P_U\right) \tag{1}$$

and the downstream agent utility is a function of their consumption and pollution,

$$U_D = U\left(C_D, P_D\right) \tag{2}$$

Utility is quasi-concave in *C* and *P* for upstream and downstream agents. Pollution in the upstream country is a function of consumption C_U and environmental effort E_U,

$$P_U = P_U\left(C_U, E_U\right) \tag{3}$$

where $\left(\dfrac{\delta P_U}{\delta C_U}\right) > 0$ and $\left(\dfrac{\delta P_U}{\delta E_U}\right) < 0$.

Pollution in the downstream country is a function of consumption and environmental effort in the downstream country, plus the fraction of upstream pollution that travels downstream,

$$P_D = P_D\left(C_D, E_D\right) + \lambda P_U \tag{4}$$

where $\left(\dfrac{\delta P_D}{\delta C_D}\right) > 0$ and $\left(\dfrac{\delta P_D}{\delta E_D}\right) < 0$.

Income Y is spent on consumption C and environmental effort E Prices of C and E are normalized to 1 in the income constraint

$$Y_i = C_i + E_i \tag{5}$$

where $i = U,\ D$.

In a specified utility function, agent i maximizes

$$U_i = C_i - z_i P_i \tag{6}$$

where z_i is the constant marginal disutility of pollution assumed equal to one. Upstream utility

$$U_U = \delta_0 C_U - \delta_1 C_U^2 - z_U P_U \tag{7}$$

where z_U is the marginal disutility of pollution assumed equal to one. Upstream pollution is a quadratic function of consumption and environmental effort in upstream and downstream countries,

$$P_U = \gamma_0 C_U - \gamma_1 C_U^2 - E_U + \alpha_2 E_U^2 \tag{8}$$

Substituting the pollution function into the utility function utility $U_U = \left(\delta_0 - \gamma_0\right) C_U - \left(\delta_1 - \gamma_1\right) C_U^2 + E_U - \alpha_2 E_U^2$. For notational convenience let $\left(\delta_0 - \gamma_0\right) = \alpha_0$ and $\left(\delta_1 - \gamma_1\right) = \alpha_1$. To ensure that the reduced form utility function is concave, assume $\alpha_0 > 0$ and $\alpha_1 > 0$ which in turn require the parameter restrictions $\delta_0 > \gamma_0$ and $\delta_1 > \gamma_1$.

The upstream agent chooses consumption and effort to maximize utility, subject to the budget constraint $Y_U = C_U + E_U$. The adding-up conditions on the solutions to this problem require the further parameter restriction that $\alpha_0 = 1$ [1]. Optimal consumption and effort levels in the upstream country are

$$C_U^* = \left(\frac{\alpha_2 Y_U}{\alpha_1 + \alpha_2}\right) \tag{9}$$

[1]To see this, note that the solutions to the problem are of the form $c_U^* = \left(\dfrac{\alpha_0 - 1 + 2\alpha_2 Y_U}{2\left(\alpha_1 + \alpha_2\right)}\right)$ and $E_U^* = \left(\dfrac{1 - \alpha_0 + 2\alpha_1 Y_U}{2\left(\alpha_1 + \alpha_2\right)}\right)$. To fulfill the budget constraint that $c_U^* + E_U^* = Y_U$ for all $Y_U > 0$ we must have $\alpha_0 = 1$.

$$E_U^* = \left(\frac{\alpha_1 Y_U}{\alpha_1 + \alpha_2}\right) \tag{10}$$

In general $U_D = f\left(C_D, P_D\right)$ or

$$U_D = \delta_2 C_D - \delta_3 C_D^2 - z_D P_D \tag{11}$$

Again z_D represents marginal disutility of pollution in the downstream country, assumed equal to one. Pollution in the downstream country is

$$P_D = \gamma_2 C_D - \gamma_3 C_D^2 - E_D + \alpha_4 E_D^2 + \lambda P_U^* \tag{12}$$

where λ represents the fraction of upstream pollution that flows downstream. For simplicity, assume $\lambda = 1$ so that all upstream pollution flows downstream. Substituting (8) into (12) expresses downstream pollution as a function of upstream and downstream consumption and environmental effort,

$$P_D = \gamma_0 C_U^* - \gamma_1 C_U^{*2} - E_U^* + \alpha_2 E_U^{*2} + \gamma_2 C_D - \gamma_3 \left(C_D\right)^2 - E_U + \alpha_2 \left(E_U^2\right)^* \tag{13}$$

The potential of diminishing returns to pollution with respect to consumption and environmental effort is preserved from the A&L model.

Substituting (13) into (11) the utility of the downstream citizen is a function of their own consumption and environmental effort as well as upstream consumption and environmental effort,

$$U_D = \left(\delta_0 - \gamma_0\right) C_U^* - \left(\delta_1 - \gamma_1\right) C_U^{*2} + E_U - \alpha_2 E_U^2 + \left(\delta_2 - \gamma_2\right) C_D - \left(\delta_3 - \gamma_3\right) C_D^2 + E_D - \alpha_4 E_D^2 \tag{14}$$

subject to the constraint on income, $Y_D = C_D + E_D$. As above, impose the parameter restrictions $\left(\delta_0 - \gamma_0\right) = 1$, $\left(\delta_2 - \gamma_2\right) = 1$, and let $\left(\delta_1 - \gamma_1\right) = \alpha_1$ and $\left(\delta_3 - \gamma_3\right) = \alpha_3$.

Treating C_U^* and E_U^* as constants and solving for optimal consumption and environmental effort in the downstream country yields

$$C_D^* = \left(\frac{\left(\alpha_4\right)}{\alpha_3 + \alpha_4}\right) Y_D \tag{15}$$

$$E_D^* = \left(\frac{\alpha_3}{\alpha_3 + \alpha_4}\right) Y_D \tag{16}$$

Substituting (9), (10), (15), and (16) in the downstream pollution function

$$P_D = \gamma_0 C_U^* - \gamma_1 \left(C_U^*\right)^2 - E_U^* + \alpha_2 \left(E_U^*\right)^2 + \gamma_2 C_D^* - \gamma_3 \left(C_D^*\right)^2 - E_D^* + \alpha_4 \left(E_D^*\right)^2 \tag{17}$$

and combining like terms and simplifying yields

$$P_D = \left(\frac{\left(\alpha_2 - \alpha_1\right)}{\alpha_1 + \alpha_2}\right) Y_U + \left(\frac{\alpha_2 \alpha_1^2 - \gamma_1 \alpha_2^2}{\left(\alpha_1 + \alpha_2\right)^2}\right) Y_U^2 + \left(\frac{\left(\alpha_4 - \alpha_3\right)}{\alpha_3 + \alpha_4}\right) Y_D + \left(\frac{\alpha_4 \alpha_3^2 - \gamma_3 \alpha_4^2}{\left(\alpha_3 + \alpha_4\right)^2}\right) Y_D^2 \tag{18}$$

Equation (18) requires the further restriction $\gamma_0 = 1$ and $\gamma_2 = 1$.

The estimated EKC model follows

$$P_D = \beta_0 + \beta_1 Y_U + \beta_2 Y_U^2 + \beta_3 Y_D + \beta_4 Y_D^2 \tag{19}$$

where P_D is BOD per capita, Y_U is upstream income, Y_D is downstream income, and $\beta' s$ are coefficients to be estimated.

Linking the theoretical model with the empirical model, the second order marginal effects of consumption and effort on utility for the upstream country α_1 and α_2 and downstream country α_3 and α_4 can be derived from the following:

$$\left(\frac{\left(\alpha_2 - \alpha_1\right)}{\alpha_1 + \alpha_2}\right) = \beta_1 \tag{20}$$

$$\left(\frac{\alpha_2\alpha_1^2-\gamma_1\alpha_2^2}{\left(\alpha_1+\alpha_2\right)^2}\right)=\beta_2 \tag{21}$$

$$\left(\frac{\left(\alpha_4-\alpha_3\right)}{\alpha_3+\alpha_4}\right)=\beta_3 \tag{22}$$

$$\left(\frac{\alpha_4\alpha_3^2-\gamma_3\alpha_4^2}{\left(\alpha_3+\alpha_4\right)^2}\right)=\beta_4 \tag{23}$$

Solving for α_3 in terms of β_3, β_4, and γ_3 yields

$$\alpha_3=\left(\frac{4\beta_4+\gamma_3\left(1+\beta_3\right)^2}{\left(1-\beta_3\right)^2}\right) \tag{24}$$

The parameter γ_3 is unknown. The parameter γ_3 can take any positive value as long as $\left(\frac{\delta U_D}{\delta C_D}\right)>0$. Let $\gamma_3=0.5$. Once α_3 is solved, the following expression can solve for α_4:

$$\alpha_4=\left(\frac{\alpha_3\left(1+\beta_3\right)}{1-\beta_3}\right). \tag{25}$$

The parameters α_1 and α_2 can be solved using β_1 and β_2 in a similar manner.

Although this model is somewhat restrictive, this appears to be the first attempt to link a theoretical model of an EKC with an empirical model. This is important because the underlying causes of an EKC are debated. Some EKC theorists believe citizens make "greener" consumption choices as they grow richer, while other theorists believe the EKC is a reflection of harsher environmental regulations in higher income countries. The EKC empirical estimates can derive underlying second order effects of consumption and effort on utility. Results may offer insight into how consumers value consumption and effort and where their income should be spent.

3. Conclusion

This paper investigates downstream dependence in an EKC for water pollution. The question this paper addresses is whether downstream pollution can be redressed with income growth in the upstream country. A theoretical model is developed that relates theoretical parameters directly with the typical empirically estimated parameters of the reduced form EKC model. Theoretical parameters for upstream and downstream county consumption and environmental effort are derived. Future EKC studies may benefit from employing the theoretical model proposed in this paper to help devise appropriate policy for various pollution indicators.

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