

Chapter 2

Environmental Kuznets Curve Hypothesis

Abstract This chapter deals with the environmental Kuznets curve (EKC) hypothesis, as one hypothesis that speaks to the possibility of sustainable development; this chapter also provides a brief overview and current research trends. The EKC hypothesis implies there is an inverted U-shaped relationship between environment degradation and economic development. The concept of the EKC originally began with data observation, and has attracted considerable attention from many researchers concerning the existence of the EKC—since it is very naive—and the thinking that relates to it. This chapter also surveys the main EKC research, which has been undertaken from both empirical and theoretical perspectives. As for the empirical perspective, the author compares previous studies that focus on the income level inherent in the EKC turning point. From the theoretical perspective, the author briefly introduces the Stokey (International Economic Review, 39, 1–31, [43]) model, which addresses stock pollutants. Finally, the author takes up criticisms and problems inherent in previous empirical and theoretical studies of the EKC.

Keywords Environmental Kuznets curve • Inverted U-shaped • Turning point • Carbon dioxide • Income level

2.1 Environmental Kuznets Curve Hypothesis

When considering sustainable development that will take place in the future, it is important to accurately grasp past circumstances and the present situation regarding the relationship between economic development and environmental quality. This section surveys the empirical and theoretical studies of the environmental Kuznets curve (EKC) hypothesis and points out the problems therein.

In the field of environmental economics, the EKC hypothesis is used to consider the relationship between economic growth and the environment. This hypothesis was derived through data observation. When one plots per-capita income along a horizontal axis and the per-capita index of environmental degradation on a vertical axis for a certain country, he or she will generally find a relationship that takes the form of an inverted U-shaped curve. In other words, environmental degradation increases

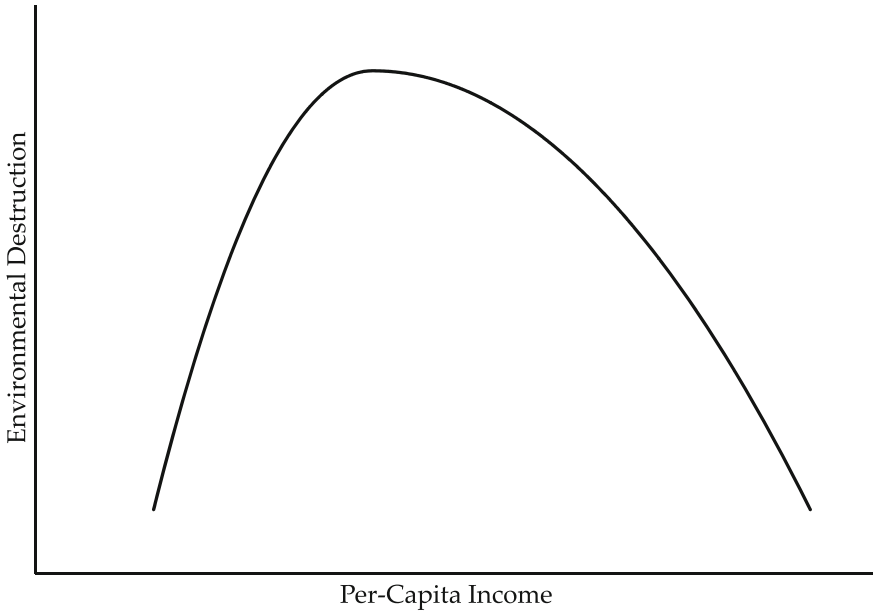


Fig. 2.1 Environmental Kuznets curve

in the early stage of economic development, and after per-capita income exceeds a certain level (i.e., turning point), it turns to decrease as income increases (Fig. 2.1). Simon Kuznets found the relationship between per-capita national income and income inequality, and he went on to present the hypothesis that the relationship grows in the early stage of economic development and shrinks in later stages [26]. This is known as the Kuznets curve hypothesis, and the EKC is an analogy of it. Recently, when considering sustainable development, it has been more important to understand the influence that economic growth has on the environment, and so the concept of the EKC has also become attractive when pursuing sustainable development.

Economic research on the EKC began with Grossman and Krueger [21] and Shafik and Bandyopadhyay [39]; the latter of these served as the background study of the report of the World Bank [47]. The concept then came to be known widely, by virtue of the World Bank. Although these studies made use of data captured through observation, their findings came to be considered pieces of evidence that suggest the feasibility of sustainable development, provided the existence of the EKC becomes clear through analysis. Moreover, there was eventually the expectation that the EKC could help predict long-term environmental changes and thus assist in crafting preventive policies. Comprehensive survey studies in this field include those of Stern [40, 41], Panayotou [32], Dasgupta et al. [11], and Dinda [14], inter alia. In

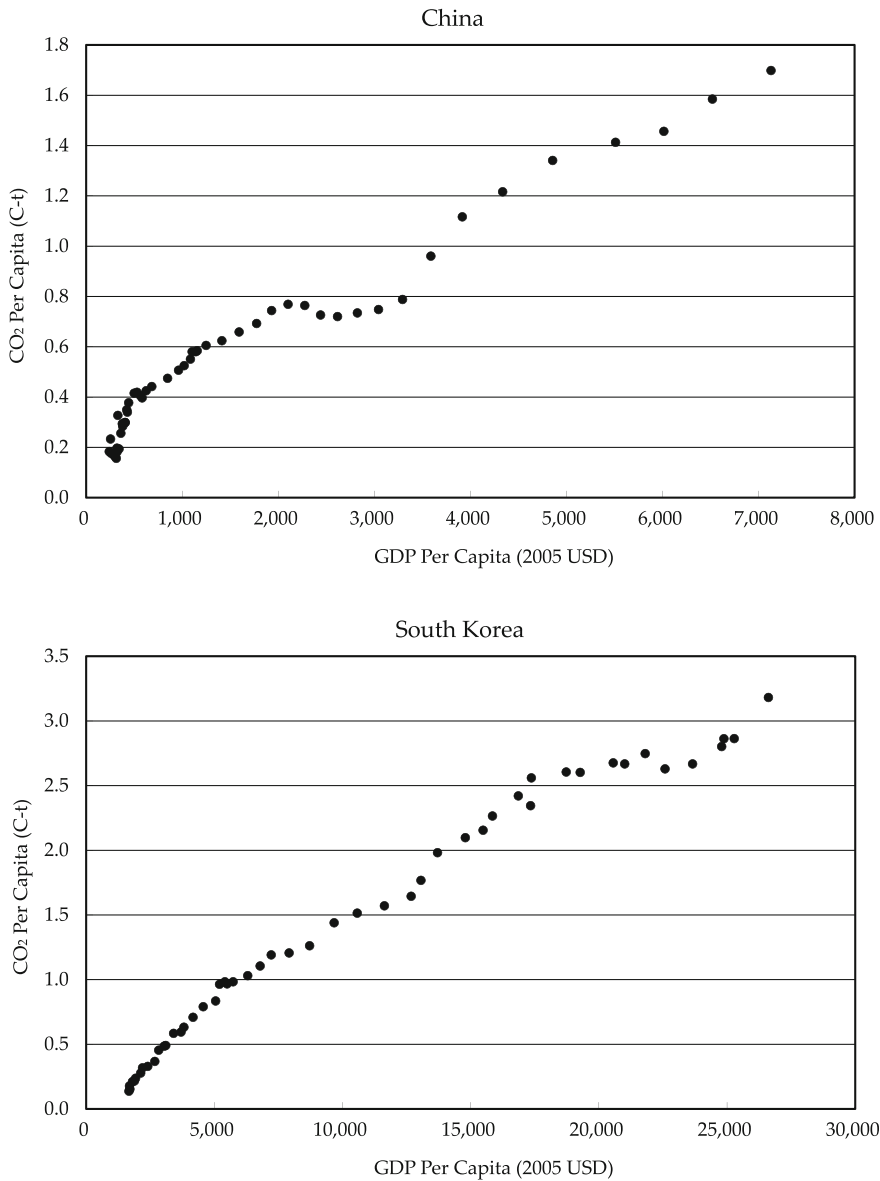


Fig. 2.2 Environmental Kuznets curve of each country (developing countries)

the late 1990s, some special issues of academic journals were dedicated to the topic of the EKC¹ and attracted considerable research interest.

¹For instance, see *Environment and Development Economics*, Vol. 2, Part 4, 1997, and *Ecological Economics*, Vol. 25, No. 2, 1998.

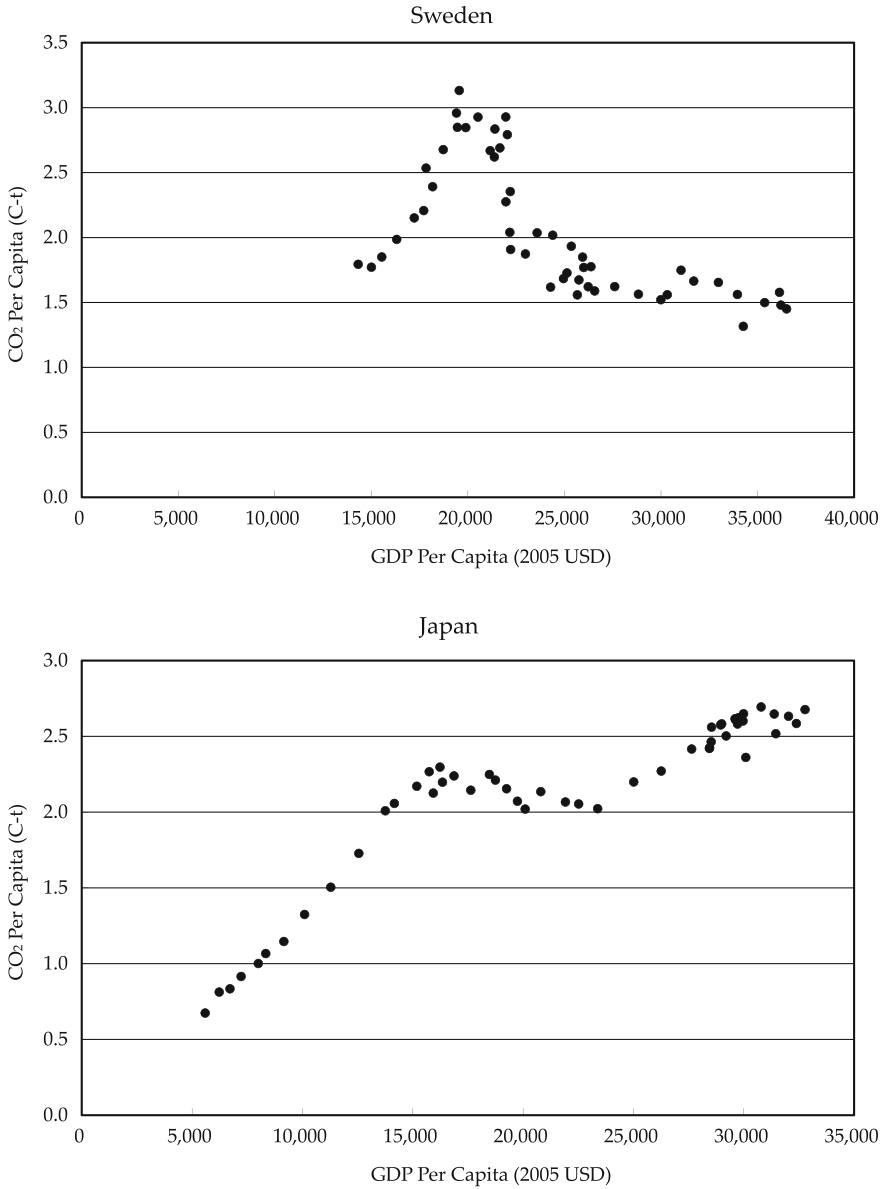


Fig. 2.3 Environmental Kuznets curve of each country (advanced countries)

Typical EKC patterns are shown in Fig. 2.1. The pattern for each country becomes part of the inverted U-shaped curve naturally, in line with that country’s stage of economic development. The author takes up the cases of Sweden, Japan, South Korea, and China. Figures 2.2 and 2.3 plot the relationship between per-capita carbon

dioxide (CO₂) emissions and the real GDP of the countries. China, a developing country, generally shows an upward-sloping curve. Although it shows a downward slant just after the Asian currency crisis, it returned to an upward slant more recently, and the rate of increase in CO₂ emissions per GDP has also increased. South Korea is treated as a developing country in this study, as it has been classified as part of the non-Annex I group of the Framework Convention on Climate Change—although South Korea could be considered an advanced nation, given its OECD membership. Looking at the figure of South Korea, one can find a consistent upward slanting curve, as if South Korea were a developing country. Although a fall in CO₂ emissions in both South Korea and China was seen at the time of the Asian currency crisis, the figure shows an upward rise in South Korea recently, and it has not yet reached the turning point. Sweden, an advanced nation in northern Europe that is seen as very environmentally conscious, reached its turning point after an upward sloping curve; it seems to now be in the downward-sloping stage. Sweden's CO₂ emissions are decreasing, concurrent with an increase in income, and the full EKC is obvious. Although Japan is also an advanced nation, its figure differs from that of Sweden. CO₂ emissions in Japan increased during the period of high economic growth, as income increased. The amount of emissions came to decrease along with an increase in income, probably because energy-saving progressed after the two oil crises—that is, the EKC of Japan seemed to appear, along with a turning point. However, the emissions increased again after the bubble economy period, when the EKC took on the appearance of one from a developing country. As a result, it takes on more of an N-shaped curve than an inverted U-shaped curve. Not only income but also the industrial structure of each of economy, energy composition, trade, and others is considered a factor that brings about this different shape. Analysis has also been directed toward such factors.

2.2 Literature Review (1): Empirical Research

To date, many studies have undertaken empirical analyses of the EKC. There are some reasons for this research interest. The studies in this field began with empirical analyses, and researchers are interested in the EKC because the underlying concept is naïve and imperfect and has many unresolved points.² Since it is difficult to cover such a large body of work in its entirety, the author will introduce some of the more typical studies.

In general, empirical studies have sought to explain per-capita environmental degradation level by way of a polynomial equation of per-capita income, ever since the pioneering research of Grossman and Krueger [21].³ A standard regression model

²As mentioned in Sect. 2.5, many problems have been pointed out with regard to the EKC.

³Some empirical studies employ per-income CO₂ emissions as a dependent variable. However, this is an index of energy efficiency, and so it may be inappropriate as an index of environmental degradation level.

is as follows, and it has recently been used with panel data in many empirical studies.

$$E_{it} = \beta_0 + \beta_1 y_{it} + \beta_2 y_{it}^2 + \beta_3 y_{it}^3 + \beta_4 x_{it} + u_{it}, \quad (2.1)$$

where E denotes the index of environmental pollution, y expresses per-capita income, and x is other control variables. Moreover, i denotes countries, and t is time.

If $\beta_1 > 0$, $\beta_2 < 0$, and $\beta_3 = 0$ with statistical significance, and the turning point where the pollution level starts to fall is within a reasonable range, the EKC is thought to exist. In the model of Eq. (2.1), the per-capita income level of the turning point is given by $(-\beta_1/(2\beta_2))$. The major concern of empirical analyses is how high the income level is that corresponds to the turning point.

When analyzing natural resources like forests, not a standard model resembling Eq. (2.1) but rather a log-linear and semi-log-type model is often used, as the dependent variable cannot be allowed to fall below zero.

In the case of $\beta_3 > 0$ with statistical significance, the decrease in the pollution level—along with an increase in income—is considered temporal; conversely, the pollution level will worsen at a stage where there is higher income. That is, this type of estimation model is based on the hypothesis that the EKC is an N-shaped curve.⁴ x is introduced to control the variables that can affect both the environment and income (e.g., trade and energy prices). Agras and Chapman [1] survey the effect of explanatory variables other than income, and conclude that income has the greatest explanatory power. The results of Stern [40] and Neumayer [30] align with this result.

The techniques used in empirical studies can be classified into a few different categories. The first is the country-based category, where EKC estimates are drawn for the whole world or specific countries. From the 1990s to the 2000s, many studies focused on estimating the EKC of the whole world. These studies assume that all countries have the same locus. As one can easily imagine, however, various conditions—such as natural conditions and social situations, all of which can affect economic development—differ among countries in reality. Moreover, in developing countries, there is the considerable possibility that the curve can shift to the lower left on account of the so-called latecomer advantage. Numerous research studies that examined EKC estimations by using data from specific countries have been published; Al-Mulali et al. [2] provides a review of such studies.

The second category is that based on data characteristics and estimation methods. The per-capita income and pollution level data may be nonstationary; when data are nonstationary, regression analysis can give rise to spurious correlation, and results can be rendered meaningless. To preclude this, some studies test data stationarity, and then employ the autoregressive distributed lag (ARDL) model or error-correction model after confirming cointegration. Wagner [46] carries out panel unit root tests and panel cointegration tests for CO₂. Agras and Chapman [1] and Al-Mulali et al. [2] are studies that make use of the ARDL model. As for estimation methods, some

⁴Grossman and Krueger [22] and Vincent [45] each employed a cubic polynomial model while assuming an N-shaped EKC; each obtained statistically significant results. As shown in Fig. 2.3, the Japanese CO₂ data seem to illustrate an N-shaped curve.

studies use a nonparametric method—which is flexible for estimation (e.g., Ordás Criado [31])—or a calibration method (e.g., Egli and Steger [17]; Bartz and Kelly [5]).

To date, empirical studies have addressed atmospheric quality, water quality, waste, city sanitation, and energy use. Especially, many have focused mainly on air quality, such as sulfur dioxide (SO_2), nitrogen oxide (NO_x), carbon monoxide (CO), suspended particulate matter (SPM), and CO_2 .

The following are typical studies on air quality, on elements other than CO_2 . Selden and Song [36] conducted analyses of SO_2 , SPM, NO_x , and CO , and conclude the existence of the EKC. The turning point is a level at around USD10,000 (1985 constant prices). The characteristic point is adding population density to the explanatory variables. Grossman and Krueger [22] investigated 14 kinds of environmental indicators with regard to air quality and river water quality, and confirm the formation of the EKC for almost all the environmental indicators; there, for many environmental indicators, the turning point is less than USD8,000 (1985 constant prices). Cole et al. [9] used some additional explanatory variables and support the formation of the EKC for local air pollution. Although the turning point differs with the pollutant, it was found to range from USD6,000 to USD18,000 (1985 constant prices), which is within the range of the sample. Stern and Common [42] targeted sulfur emissions and found the existence of an inverted U-shaped curve; they also show that the turning point is at a level (USD9,181; 1990 constant prices) appropriate to their sample of OECD countries, and that the turning-point level becomes extremely high with a monotonic increase for the whole world and for the sample of non-OECD countries. Thus, it is clear that sample selection bears an important influence.

As mentioned, regarding some environmental indicators of the air pollutants that have direct effects on human health, plenty of studies support the formation of the EKC. However, no consensus has been reached about the turning-point level at which environmental improvements start.

On the other hand, few studies address global pollutants such as CO_2 , compared to other local air quality factors, and researchers have not reached a clear consensus about EKC formation. As for CO_2 , some typical studies are as follows.⁵ Shafik [38] builds upon the report of the World Bank [47] and illustrates an EKC with a monotonic increase. Holtz-Eakin and Selden [23] find an inverted U-shaped relationship, but an extremely high turning point of USD35,428 to USD8 million (1985 constant prices) or more; in other words, this is substantively equal to a monotonic increase. Schmalensee et al. [35] confirm the negative income elasticity of environmental pollution in high-income countries, and this supports the existence of the EKC with a reasonable turning point.

⁵Previous empirical studies investigated only CO_2 emissions; to the best of the author's knowledge, no research has been undertaken that considers the source of CO_2 absorption.

Agras and Chapman [1] adopted energy price and the trade-GDP ratio as explanatory variables, and applied the ARDL model (ARDL(1,0)) to analyze the dynamic process. Their results point out that the energy price can serve as an important explanatory variable, and that the turning point is USD13,630 (1985 constant prices). Neumayer [30] applied natural factors such as temperature and the rate of growth of a country's economic activity area to the explanatory variables. Although Cole [7] considers the influence of trade and shows the formation of the EKC, the turning point differs with the combination of explanatory variables adopted, and thus ranges from USD20,352 to USD56,696 (1985 constant prices).

Dijkgraaf and Vollebergh [13] obtained USD20,600 (1990 constant prices) as the turning point, and found that the estimated parameters of each country are not homogeneous. This means that there is no EKC common to each country, and they insist that it is necessary to allow heterogeneity in the income parameters and in the individual effects of each country. Richmond and Kaufmann [34] adopted the share of various kinds of fuels as explanatory variables, to preclude variable lack bias. Although they confirmed the formation of the EKC with turning points of USD29,687 and USD25,450 (1996 constant prices) for the whole world and for OECD members, respectively, they could not show the existence of the EKC through the use of a non-OECD sample. Galeotti et al. [20] compared the estimation results by using data from the International Energy Agency (IEA) and from the Oak Ridge National Laboratory (ORNL). In addition, another characteristic of this study is the adoption of a nonlinear estimation model, which differs from a conventional polynomial equation of income. Their results support the formation of the EKC, and although the turning point differs by estimation model and data source, it ranges from USD15,698 to USD16,595 (1990 constant prices) for the sample of OECD countries, and between USD15,600 and USD21,186 for the non-OECD sample (Table 2.1).

Thus, there are two cases for the EKC, with regard to CO₂ emissions: one with an inverted-U curve, or another that is monotonically increasing. In undertaking a literature review, one can find the tendency for studies whose estimation period ends in 1995 or later to conclude on the existence of the EKC. Note, however, that most of those studies' estimated turning points are over USD20,000; this level is high, compared to those of other pollutants. Some studies point out that the EKC with regards to CO₂ is not observed for the whole world, even if it is observed for individual countries.

In summary, the EKC with regards to air quality is observed when the pollution area is local, the pollutant is of a flow-type and decomposes in a relatively short time, and some regulations have already been introduced. When, as is the case with CO₂, the pollutant is of a stock-type and few regulations have been introduced, the existence of the EKC remains controversial.

Table 2.1 Empirical studies of the environmental Kuznets curve for carbon dioxide

	Data source	Data period	Countries	Shape of the curve	Turning point	Characteristics of the model
Shafik [38]	ORNL PWT	1960–1989	153	Monotonic increase	N.A.	
Holtz-Eakin and Selden [23]	ORNL PWT	1951–1986	130	(Inverted-U)	35,428–8,000,000 (1985 USD)	Concluding monotonic increase substantively
Cole et al. [9]	ORNL PWT	1960–1991	7 regions	(Inverted-U)	25,100–62,700 (1985 USD)	Concluding monotonic increase substantively
Schmalensee et al. [35]	ORNL PWT	1950–1990	141	Inverted-U	N.A. (1985 USD)	
Agras and Chapman [1]	ORNL PWT, UN	1971–1989	34	Inverted-U	13,630 (1985 USD)	Employing trade indicators and energy price in ARDL model
Galeotti and Lanza [19]	IEA OECD	1971–1996	110	Inverted-U	15,073–16,646 (1990 USD)	Employing nonlinear model
Neumayer [30]	ORNL PWT	1960–1988	106	(Inverted-U)	N.A. (1985 USD)	Considering natural factors and concluding monotonic increase substantively
Cole [7]	ORNL PWT	1975–1995	32	Inverted-U	20,352–56,696 (1985 USD)	Considering trade
Dijkgraaf and Vollebergh [13]	OECD	1960–1997	24	(Inverted-U)	20,647 (1990 USD)	No EKC is estimated with common parameters of income for each country
Richmond and Kaufmann [34]	IEA PWT	1973–1997	36	Inverted-U	29,687 (1996 USD)	Employing the share of fuel types
Galeotti et al. [20]	IEA, ORNL OECD, WDI	1960–1997	N.A.	Inverted-U	15,600–21,186 (1990 USD)	Employing nonlinear model

Note ORNL Oak Ridge National Laboratory, PWT Penn World Table, WDI World Development Indicators
The parenthesis in the Shape of the Curve implies the external formation of the inverted-U curve, not the substantive one

2.3 Literature Review (2): Theoretical Research

As seen in Sect. 2.2, plenty of empirical studies have been actively undertaken since the emergence of the EKC concept, and they are based on various environmental indices. In that sense, the EKC can be said to encompass “stylized facts”, so to speak. Although there were nothing more than a few theoretical analyses of the EKC in the early 1990s, many theoretical studies that offer consistent explanations of the stylized facts have been published since the mid-1990s, along with an increase in the need for a theoretical background.

Many theoretical models have been built and can be classified into a few different categories. The most common classification is the static model versus the dynamic model.⁶ Various theoretical studies with the background of a dynamic model have been presented so far; they attempt to describe changes in environmental quality in the process of a country’s economic development, over time.

John and Pecchenino [24] adopted an overlapping generations model and derived the EKC of stock-type pollution, which is discharged mainly with consumption. Selden and Song [37] applied a modified Ramsey–Cass–Koopmans model—which is based on Forster [18]—and analyzed flow-type pollution emits from production processes. They conclude that there is the possibility of an inverted U-shaped curve emerging, under some conditions. Stokey [43] introduced the *AK* model and the Ramsey–Cass–Koopmans model; that study assumes pollution is discharged from production processes and analyzes the pollution of both flow and stock types. That study also suggests that to improve social welfare, environmental regulations that reduce pollutant emissions should be introduced.

Lopez [28] and Bulte and van Soest [6] each address the depletion of natural resources. Dinda [15] employed the framework of an endogenous growth model to examine the stock-type environment; this is used for both production and the abatement of pollution.

Lopez [28] and Stokey [43] made use of both static models and the aforementioned dynamic models. There are other static models, as follows. Lieb [27], in an extension of the static model of McConnell [29], analyzed pollution arising from consumption, and shows that the satiation of consumption is a necessary and sufficient condition for the existence of the EKC. This condition is drawn from the assertion that the increment of income turns, to be spent on pollution abatement. Andreoni and Levinson [3] indicate that economies of scale in pollution abatement are sufficient conditions for the existence of the EKC.

Some explanations have been given for the formation of an inverted U-shaped curve. Andreoni and Levinson [3] offer the following: (1) changes of composition of production and consumption, (2) a stronger preference for the environment, (3) the introduction of institutions that internalize external diseconomies, and (4) the effects of increasing returns to scale in abatement activities. de Bruyn and Heintz [12] point out five factors: (1) behavioral change and preference, (2) institutional

⁶Other classifications commonly seen are macroeconomic versus microeconomic, long-term versus short-term, and deterministic versus stochastic, among others [25].

changes, (3) technological and organizational changes, (4) structural changes, and (5) international reallocation. As mentioned, various models have been used in the theoretical derivation of the EKC, but they are contingent on the assumptions or values of parameters. To clarify this point—and also to consider the relationship with the empirical analyses in Chap. 3—the author will survey a typical theoretical model.

2.4 The Model with Stock Pollutants

This section surveys the study of Stokey [43] as a typical study that derives the EKC theoretically, and within the framework of optimum growth theory.

Stokey [43] presents four kinds of models—namely, the (a) static model, (b) dynamic model with flow-type pollutants, (c) dynamic model of (b) with exogenous technological progress, and (d) dynamic model with stock-type pollutants. Global warming relates to the accumulation in the atmosphere of greenhouse gases like CO_2 ; therefore, the author surveys a (d)-type model, which is conscious of the stock pollutant CO_2 .

In this model, the following Cobb–Douglas production function with exogenous technological progress is assumed:

$$Y(t) = Ae^{gt} K(t)^\alpha L^{1-\alpha} z(t), \quad (2.2)$$

where $Y(t)$ is output, A denotes the parameter of productivity, g represents the exogenous rate of technological progress,⁷ $K(t)$ is the amount of capital stock, and $L(t)$ is the labor input of the economy. α is assumed to $\alpha \in (0, 1)$.

$z(t)$ is the index of environmental technology and is $z(t) \in [0, 1]$. $z(t) = 1$ expresses the production technology with the maximum pollutant emissions; conversely, $z(t) = 0$ means the cleanest production technology is employed.

Pollutants are discharged only from the production process; the author does not address cases such as the waste problem, where consumption affects the environment. The pollution emission function is:

$$x(t) = Ae^{gt} K(t)^\alpha L^{1-\alpha} z(t)^\beta, \quad (2.3)$$

⁷Stokey [43] adopts the AK model with an environmental constraint to models (a) and (b). According to these models, the economy converges to the steady state, in which the growth rates of all the variables are zero as a result. This is because, as shown later, the marginal productivity of capital ($\partial Y(t)/\partial K(t) = \partial(AK(t)z(t))/\partial K(t) = Az(t)$) monotonically decreases as $z(t)$ monotonically decreases over time. This means that the long-term growth rate of the economy becomes zero and sustainable development becomes infeasible. To modify this, exogenous technological progress is introduced to models (c) and (d). The exogenous technological progress brings about increased productivity, and compensates for the fall in $z(t)$; hence, the growth rate becomes positive in the steady state.

where $x(t)$ is the emission of pollution flow in each time period, β is the parameter that shows the relationship between environmental technology and pollution flow, and $\beta > 1$.

When $z(t) = 1$, the output and emission become the maximum. Stokey [43] describes the output at this time as “potential output”. If $z(t)$ falls from 1, the environment improves with the introduction of cleaner technologies, but the output decreases. When $z(t) = 0$, both the output and emissions reach zero.

The per-capita output is:

$$y(t) = Ae^{gt}k(t)^\alpha z(t), \quad (2.4)$$

where $y(t) \equiv Y(t)/L$ denotes per-capita output, and $k(t) \equiv K(t)/L$ is the per-capita amount of capital stock. Then, the author can write Eq. (2.3) as

$$x(t) = Ae^{gt}k(t)^\alpha Lz(t)^\beta. \quad (2.5)$$

The instantaneous utility function of the representative agent with an infinite horizon at time t is

$$u(t) = \frac{c(t)^{1-\sigma} - 1}{1-\sigma} - \frac{B}{\gamma} X(t)^\gamma, \quad (2.6)$$

where $u(t)$ expresses the utility of the representative agent, $c(t)$ is per-capita consumption, σ denotes the parameter of the Arrow–Pratt measure of relative risk aversion (inverse of the intertemporal elasticity of substitution of consumption), and $\sigma > 0$. B and γ are the parameters that express disutility from pollution stock, and $B > 0$ and $\gamma > 1$. $X(t)$ shows the level of pollution stock in the economy.

The first term on the right-hand side of Eq. (2.6) is a standard constant relative risk aversion (CRRA) utility function; the second term is the additively separable utility function that expresses the disutility from pollution stock. An increase in pollution reduces the utility of the consumer, and increases the marginal disutility. Thus, the utility of the representative agent is influenced by the environmental level.

The accumulation equation of pollution is as follows:

$$\dot{X}(t) = x(t) - \eta X(t), \quad (2.7)$$

where η expresses the degree of purification capacity of pollution (or depollution ratio), and $\eta \in [0, 1]$.⁸

The accumulation equation of capital is

$$\dot{K}(t) = Ae^{gt}K(t)^\alpha L^{1-\alpha}z(t) - \delta K(t) - C(t),$$

⁸If $\eta = 1$, this refers to the specific case of flow-type pollution, since the pollution stock will be removed during this term.

namely,

$$\dot{k}(t) = Ae^{gt}k(t)^\alpha z(t) - \delta k(t) - c(t), \quad (2.8)$$

where δ is the depreciation rate, $\delta \in [0, 1]$, and $C(t) \equiv c(t)L$ expresses the total amount of consumption.

Under the above setup, a social planner solves the following maximization problem:

$$\begin{aligned} \max \quad & \int_0^\infty e^{-\rho t} \left(\frac{c(t)^{1-\sigma} - 1}{1-\sigma} - \frac{B}{\gamma} X(t)^\gamma \right) dt \\ \text{subject to} \quad & \dot{k}(t) = Ae^{gt}k(t)^\alpha z(t) - \delta k(t) - c(t) \\ & \dot{X}(t) = Ae^{gt}k(t)^\alpha Lz(t)^\beta - \eta X(t) \\ & k(0) = k_0, \quad X(0) = X_0, \end{aligned}$$

where ρ is a subjective discount rate and $\rho \in (0, 1)$.

The following conditions are satisfied on the optimal path to the steady state (see Appendix A.1):

$$c(t) = \lambda(t)^{-\frac{1}{\sigma}} \quad (2.9)$$

$$z(t) = \begin{cases} 1 & (\text{for } \lambda(t) \geq \mu(t)\beta L) \\ \left(\frac{\lambda(t)}{\mu(t)\beta L} \right)^{\frac{1}{\beta-1}} & (\text{for } \lambda(t) < \mu(t)\beta L) \end{cases} \quad (2.10)$$

$$\frac{\lambda(t)}{\lambda(t)} = \begin{cases} \rho + \delta - \alpha \left(1 - \frac{\mu(t)L}{\lambda(t)} \right)^{\frac{y(t)}{k(t)}} & (\text{for } z(t) = 1) \\ \rho + \delta - \alpha \left(1 - \frac{1}{\beta} \right)^{\frac{y(t)}{k(t)}} & (\text{for } z(t) < 1) \end{cases} \quad (2.11)$$

$$\frac{\mu(t)}{\mu(t)} = \rho + \eta - \frac{BX(t)^{\gamma-1}}{\mu(t)}, \quad (2.12)$$

where $\lambda(t)$ and $\mu(t)$ represent the shadow price of capital $k(t)$ and pollution stock $X(t)$, respectively.

Next, the author examines the dynamics of each variable. As there are two state variables in this model—namely, $k(t)$ and $X(t)$ —it is impossible to undertake analysis based on phase diagrams. Therefore, the author focuses on some variables of consideration. Suppose that the initial value of capital, $k(0) = k_0$, takes a smaller value than the value at the steady state. Then the shadow price $\lambda(0)$ of capital $k(0)$ is sufficiently larger than the shadow price μ of pollution stock $X(0)$ —and, as a result, $z(0)$ becomes 1. $k(t)$ increases over time to the steady state. If t is sufficiently small (i.e., the economy is in an early stage of development), $k(t)$ is small and $z(t) = 1$. When $z(t) = 1$, $y(t)$, $k(t)$, and $x(t)$ also increase over time. However, as capital accumulation progresses, $\lambda(t)$ decreases and $\mu(t)$ increases. Eventually, $\mu(t)$ exceeds $\lambda(t)$, and then $z(t) < 1$. After that, $z(t)$ decreases over time. In this situation, there is the possibility of reduced pollution.

Next, the author examines the long-term growth rate of the economy, while focusing on the steady state. This economy converges the unique steady state. The growth rates of $y(t)$, $k(t)$, and $c(t)$ are the same, and given by the following formula:

$$g_y = \frac{\gamma(\beta - 1)g}{(1 - \alpha)\gamma(\beta - 1) + (\gamma + \sigma - 1)}, \quad (2.13)$$

where $g_\bullet$ expresses the growth rate with regard to the suffix variables (e.g., $g_y \equiv \dot{y}/y$). Then, the author has the following as the change rate of pollutant emissions (see Appendix A.2):

$$g_x = g_x = \frac{1 - \sigma}{\gamma} g_y. \quad (2.14)$$

Therefore, if and only if $\sigma > 1$, Eq. (2.14) derives a negative value, and pollution flow and pollution stock decrease in the long run. This implies that the EKC shows a downward-sloping curve.⁹

In summary, although pollution emissions increase with an increase in production in a country's early stage of economic development, pro-environmental production technology will be introduced and pollution emissions will decrease after economic development has reached a certain level. Moreover, both pollution flow and pollution stock decrease in the steady state, and this implies that the EKC is derived theoretically. Note that this depends on conditions regarding the inverse of the intertemporal elasticity of substitution of consumption, σ . Figure 2.4 is a pattern diagram of the EKC, derived theoretically through this model.

2.5 Problems with the Environmental Kuznets Curve

There have been numerous empirical and theoretical EKC studies. On the other hand, many criticisms have also been presented thus far—many of which argue that the EKC bears a very naive hypothesis. This section surveys the problems and criticisms of the concept, as well as academic results regarding the EKC.

2.5.1 Conceptual and Theoretical Aspects

When the EKC hypothesis is understood obediently, its main points can be summarized as follows. First, in the early stage of development, since economic growth and the environment have a trade-off relationship, some environmental pollutions are

⁹As is obvious from Eqs. (2.13) and (2.14), η is not included in either the long-run growth rate or the change rate of pollutant emissions. That is, whether the pollution type is flow or stock does not matter with respect to the long-run growth rate or the change rate of pollutant emissions. In addition, the depreciation rate, δ , has no impact on them, either.

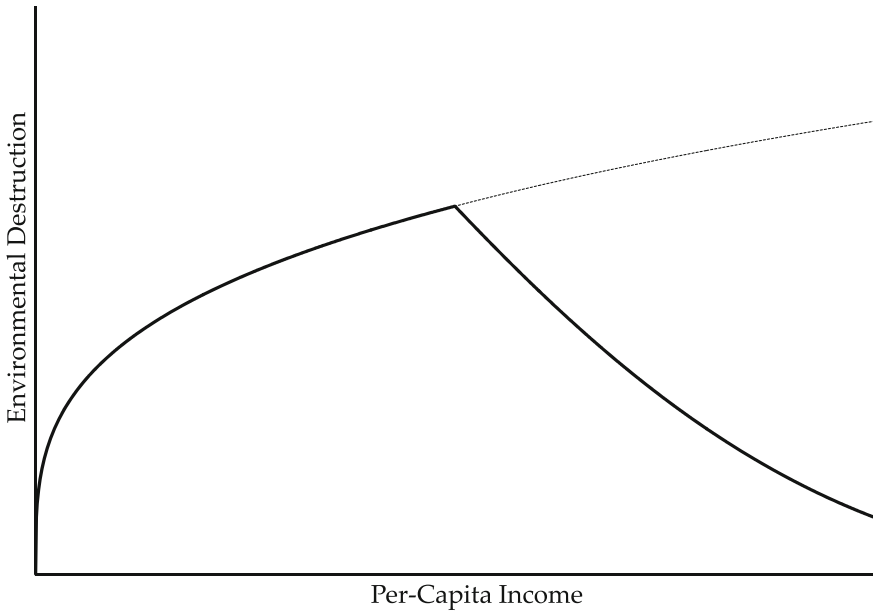


Fig. 2.4 Environmental Kuznets curve (Stokey model)

unavoidable during growth. However, that pollution may also produce permanent environmental destruction. Second, as pollution increases, the environment becomes a relatively rare resource, and so its value increases. Moreover, since appropriate measures against pollution control come to be taken with the accumulation of capital, economic growth and environmental preservation come to coexist.

One may be skeptical of these points. Arrow et al. [4], a pioneer of criticism, states that “While they [=empirical findings] do indicate that economic growth may be associated with improvements in some environmental indicators, they imply neither that economic growth is sufficient to induce environmental improvement in general, nor that the environmental effects of growth may be ignored”.¹⁰ It is quite natural that people would not rely solely on economic development and, needless to say, that certain measures by which to improve the environment would be indispensable. Moreover, other studies also point out various problems inherent in the EKC, based on the views of Arrow et al. [4]. Such criticisms and problems can be summarized as follows.

First, the interdependence of economy and the environment has not been taken into consideration. In empirical studies, income is considered an exogenous variable that affects the environment unilaterally. In reality, however, a path in the opposite direction—from the environment to the economy—can also be considered. For example, a typical case is that environmental destruction can inhibit economic growth.

¹⁰Arrow et al. [4], p. 520.

Therefore, it is necessary to consider the influence of both path directions between the economy and the environment.

Second, neither emissions of alternative pollutants nor discharges in foreign countries have been taken into consideration. Usually, reduced pollution levels are brought about by the introduction of environmental regulations and technological progress. In some situations, however, there is the possibility that reductions in a certain pollutant will bring about the emission of alternative pollutants. Moreover, tighter pollution-emission regulations in a certain country may increase emissions in a foreign country that has looser regulations. Thus, by inducing other problems, some cases that give rise to neither improvements nor sustainability may come to pass.

Third, the effects of trade have not been taken into consideration. Developing countries with relatively abundant labor and natural resources have an advantage with respect to pollution-intensive production, compared to advanced countries with abundant human resources. Suppose trade is based on a comparative advantage: developing countries with low incomes and a weak preference for the environment will specialize in pollution-intensive industries and hence increase pollution. Moreover, the tightening of regulations in an advanced nation may drive domestic pollution-intensive industries to relocate to countries with looser regulations. However, few studies analyze the influence of such leakage.

Fourth, differences in income distribution within each country have not been taken into consideration. Worldwide, income distribution is not uniform, and a large proportion of the world's population belongs to low-income developing countries. Therefore, even if the existence of the EKC were confirmed, the worldwide pollution level is expected to worsen over a considerably long period of time, if those countries located on the upward-sloping part of the EKC continue to grow economically.¹¹

As to why the EKC forms, to date, not many theoretical analyses have focused on industrial structure, trade structure, or institutional aspects.¹²

2.5.2 *Empirical Aspects*

With respect to empirical studies of the EKC, the following have been highlighted as problematic. One large problem relates to model formulation. To date, there have been few empirical studies in line with the theoretical model. The standard regression model is a reduced-form model like Eq. (2.1), which uses per-capita income as an explanatory variable.

Hence, it is difficult to make economic interpretations of the value of the estimated parameters, and so there is a gap between the theoretical and empirical results. This type of estimation model, however, is thought to be inevitable, given the availability and quality of environmental indicator data.

¹¹ See Selden and Song [36] and Holtz-Eakin and Selden [23].

¹² Even if the EKC of CO₂ were to exist, there are many criticisms that it merely reflects energy-saving after the oil crisis, rather than emissions-reduction efforts.

Moreover, many empirical studies thus far are based on worldwide panel data; there have not been many analyses at the individual country level. Estimations with panel data assume that all countries have the same locus; however, as one can easily imagine, each country has different conditions that characterize its economic development, such as natural and social conditions. In addition, there is the possibility that for a developing country, an EKC will shift to the lower left, owing to the so-called latecomer advantage. Therefore, some researchers have posed questions regarding the methods used in panel data analysis. Dijkgraaf and Vollebergh [13] argue that the estimation of homogeneous parameters by using panel data is inappropriate, and they question the existence of the EKC.

As for modeling, the question of omitted variable bias has also been raised. Some other variables—such as trade and energy price, which may affect environmental indicators as well as income—are frequently omitted when estimating a polynomial equation of income.¹³ Few studies within the EKC literature analyze changes in industrial structure or institutions. This is also considered an omitted variable bias problem, and it stems from data unavailability.

Furthermore, there is the problem of simultaneity. Although the reduced-form model implicitly assumes causality from income (on the right-hand side) to the environment (on the left-hand side), there can also be causality in the reverse direction; simultaneous determination is also possible.¹⁴ For this reason, there is a need for an estimation method that considers simultaneity.

Another problem is heteroskedasticity. This problem generally persists in analyses of panel data, as such analyses focus on differences among individuals. As for the EKC, it is natural to consider that the social conditions of each country and which underlie the EKC will differ.

Moreover, as Stern and Common [42] point out, there is the problem of data stationarity. To date, this problem has not been overly conspicuous in the empirical EKC studies. Recently, a few research studies—such as those of Perman and Stern [33], Cole [7] (whose target is CO₂), Dinda and Coondoo [16], and Richmond and Kaufmann [34]—perform unit root tests and cointegration tests.

As mentioned, some problems persist in the estimation results reported thus far. However, even when a researcher attempts to improve the analytical methods, he or she is compelled to face the difficulties and limits inherent in empirical analysis, as the available environmental data are quite insufficient, both qualitatively and quantitatively. Therefore, based on current research trends, it is not necessarily easy to perform adequate empirical studies of environmental problems—especially of the global warming issue—while bearing in mind the issue of sustainable development.

¹³Suri and Chapman [44] and Cole [7, 8] each add a trade indicator to their explanatory variables. Richmond and Kaufmann [34] employ an energy consumption variable. Neumayer [30] considers natural factors such as temperature.

¹⁴Coondoo and Dinda [10] adopt a Granger causality test for income and CO₂ emissions, using 1960–1990 data. They report no causality, or causality from income to CO₂ emissions, in developing countries, as well as causality from CO₂ emissions to income in advanced countries.

References

1. Agras, J., & Chapman, D. (1999). A dynamic approach to the environmental Kuznets curve hypothesis. *Ecological Economics*, 28, 267–277.
2. Al-Mulali, U., Saboori, B., & Ozturk, I. (2015). Investigating the environmental Kuznets curve hypothesis in Vietnam. *Energy Policy*, 76, 123–131.
3. Andreoni, J., & Levinson, A. (2001). The simple analytics of the environmental Kuznets curve. *Journal of Public Economics*, 80, 269–286.
4. Arrow, K. J., Bolin, B., Costanza, R., Dasgupta, P., Folke, C., Holling, C. S., et al. (1995). Economic growth, carrying capacity and the environment. *Science*, 268, 520–521. Reprinted in *Ecological Economics*, 15, 91–95, in *Environment and Development Economics*, 1, 104–110, and in *Ecological Applications*, 6, 13–15.
5. Bartz, S., & Kelly, D. L. (2008). Economic growth and the environment: Theory and facts. *Resource and Energy Economics*, 30, 115–149.
6. Bulte, E. H., & van Soest, D. P. (2001). Environmental degradation in developing countries: Households and the (reverse) environmental Kuznets curve. *Journal of Development Economics*, 65, 225–235.
7. Cole, M. A. (2003). Development, trade, and the environment: How robust is the environmental Kuznets curve? *Environment and Development Economics*, 8, 557–580.
8. Cole, M. A. (2004). Trade, the pollution haven hypothesis and the environmental Kuznets curve: Examining the linkages. *Ecological Economics*, 48, 71–81.
9. Cole, M. A., Rayner, A. J., & Bates, J. M. (1997). The environmental Kuznets curve: An empirical analysis. *Environment and Development Economics*, 2, 401–416.
10. Coondoo, D., & Dinda, S. (2002). Causality between income and emission: A country group-specific econometric analysis. *Ecological Economics*, 40, 351–367.
11. Dasgupta, S., Laplante, B., Wang, H., & Wheeler, D. (2002). Confronting the environmental Kuznets curve. *Journal of Economic Perspectives*, 16, 147–168.
12. de Bruyn, S. M., & Heintz, R. J. (2002). The environmental Kuznets curve hypothesis. In J. C. J. M. van den Bergh (Ed.), *Handbook of environmental and resource economics* (pp. 656–677). Oxford: Edward Elgar.
13. Dijkgraaf, E., & Vollebergh, H. R. J. (2005). A test for parameter homogeneity in CO₂ panel EKC estimations. *Environmental and Resource Economics*, 32, 229–239.
14. Dinda, S. (2004). Environmental Kuznets curve hypothesis: A survey. *Ecological Economics*, 49, 431–455.
15. Dinda, S. (2005). A theoretical basis for the environmental Kuznets curve. *Ecological Economics*, 53, 403–413.
16. Dinda, S., & Coondoo, D. (2006). Income and emission: A panel data-based cointegration analysis. *Ecological Economics*, 57, 167–181.
17. Egli, H., & Steger, T. M. (2007). A dynamic model of the environmental Kuznets curve: Turning point and public policy. *Environmental and Resource Economics*, 36, 15–34.
18. Forster, B. A. (1973). Optimal capital accumulation in a polluted environment. *Southern Economic Journal*, 39, 544–547.
19. Galeotti, M., & Lanza, A. (1999). Richer and cleaner? A study on carbon dioxide emissions in developing countries. *Energy Policy*, 27, 565–573.
20. Galeotti, M., Lanza, A., & Pauli, F. (2006). Reassessing the environmental Kuznets curve for CO₂ emissions: A robustness exercise. *Ecological Economics*, 57, 152–163.
21. Grossman, G. M., & Krueger, A. B. (1991). Environmental impacts of a North American free trade agreement, NBER Working Paper No. 3914, NBER.
22. Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *Quarterly Journal of Economics*, 110, 353–377.
23. Holtz-Eakin, D., & Selden, T. M. (1995). Stoking the fires? CO₂ emissions and economic growth. *Journal of Public Economics*, 57, 85–101.
24. John, A., & Pecchenino, R. (1994). An overlapping generations model of growth and the environment. *Economic Journal*, 104, 1393–1410.

25. Kijima, M., Nishide, K., & Oyama, A. (2010). Economic models for the environmental Kuznets curve: A survey. *Journal of Economic Dynamics and Control*, 34, 1187–1201.
26. Kuznets, S. (1955). Economic growth and income inequality. *American Economic Review*, 45, 1–28.
27. Lieb, C. M. (2002). The environmental Kuznets curve and satiation: A simple static model. *Environment and Development Economics*, 7, 429–448.
28. López, R. (1994). The environment as a factor of production: The effects of economic growth and trade liberalization. *Journal of Environmental Economics and Management*, 27, 163–184.
29. McConnell, K. E. (1997). Income and the demand for environmental quality. *Environment and Development Economics*, 2, 383–399.
30. Neumayer, E. (2002). Can natural factors explain any cross-country differences in carbon dioxide emissions? *Energy Policy*, 30, 7–12.
31. Ordás Criado, C. (2008). Temporal and spatial homogeneity in air pollutants panel EKC estimations: Two nonparametric tests applied to Spanish provinces. *Environmental and Resource Economics*, 40, 265–283.
32. Panayotou, T. (2000). Economic growth and the environment, CID Working Paper No. 56.
33. Perman, R., & Stern, D. I. (2003). Evidence from panel unit root and cointegration tests that the environmental Kuznets curve does not exist. *Australian Journal of Agricultural and Resource Economics*, 47, 325–347.
34. Richmond, A. K., & Kaufmann, R. K. (2006). Is there a turning point in the relationship between income and energy use and/or carbon emissions? *Ecological Economics*, 56, 176–189.
35. Schmalensee, R., Stoker, T. M., & Judson, R. A. (1998). World carbon dioxide emissions: 1950–2050. *Review of Economics and Statistics*, 80, 15–27.
36. Selden, T. M., & Song, D. (1994). Environmental quality and development: Is there a Kuznets curve for air pollution emissions? *Journal of Environmental Economics and Management*, 27, 147–162.
37. Selden, T. M., & Song, D. (1995). Neoclassical growth, the J curve for abatement, and the inverted U curve for pollution. *Journal of Environmental Economics and Management*, 29, 162–168.
38. Shafik, N. (1994). Economic development and environmental quality: An econometric analysis. *Oxford Economic Papers*, 46, 757–773.
39. Shafik, N., & Bandyopadhyay, S. (1992). Economic growth and environmental quality: Time series and crosscountry evidence, World Bank Policy Research Working Paper, WPS 904.
40. Stern, D. I. (1998). Progress on the environmental Kuznets curve? *Environment and Development Economics*, 3, 173–196.
41. Stern, D. I. (2004). The rise and fall of the environmental Kuznets curve. *World Development*, 32, 1419–1439.
42. Stern, D. I., & Common, M. S. (2001). Is there an environmental Kuznets curve for sulfur? *Journal of Environmental Economics and Management*, 41, 162–178.
43. Stokey, N. L. (1998). Are there limits to growth? *International Economic Review*, 39, 1–31.
44. Suri, V., & Chapman, D. (1998). Economic growth, trade and energy: Implications for the environmental Kuznets curve. *Ecological Economics*, 25, 195–208.
45. Vincent, J. R. (1997). Testing for environmental Kuznets curves within a developing country. *Environment and Development Economics*, 2, 417–431.
46. Wagner, M. (2008). The carbon Kuznets curve: A cloudy picture emitted by bad econometrics? *Resource and Energy Economics*, 30, 388–408.
47. World Bank (1992). *World development report 1992: Development and the environment*. New York: Oxford University Press.

Environmental Kuznets Curve Hypothesis and Carbon
Dioxide Emissions

Uchiyama, K.

2016, VIII, 63 p. 6 illus., 1 illus. in color., Softcover

ISBN: 978-4-431-55919-1