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International Relations in the Environmental Kuznets Curve - Theoretical Considerations

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Gruszecki Lech[1], Jóźwik Bartosz[2], Kyophilavong Phouphet[3]

Abstract:

Purpose: *This study aims to develop the economic model of the environmental Kuznets curve that would show the effect of international trade on the environment's aggregate pollution.*
Design/Methodology/Approach: *We will examine two areas with different economic policies. Following the commonly adopted terminology, the first, more developed area will be called Home Country (Home), while the other one – Foreign Country (Foreign). Home and Foreign are placed in different environmental Kuznets curves.*
Findings: *In this economic model, the trade exchange results in increased growth of both countries, affecting the degradation of their environment, with the perspective of the turning point being crossed faster in a less developed country. This is a new point of view in the literature on the subject.*
Practical Implications: *General recommendations that can be formulated based on the model include, among others, influencing the income elasticity of demand for environmental quality. This can be done by increasing economic policies to support structural changes in the economy, get the public sector more involved in environmental protection, and raise social awareness of the necessity to protect the environment.*
Originality/Value: *The environmental Kuznets curve concept got spread at the beginning of the 1990s. However, it has not been used to refer to the effects of international economic relations, e.g., trade, which have increasingly influenced economic growth today. The model presented in the article contributes to filling this gap.*

Keywords: *Environmental Kuznets curve, EKC, aggregate environmental degradation, two-country model, international trade.*

JEL: *F64, O44, Q56.*

Paper type*: Research article.*

[1]*Associate Professor of the Institute of Economics and Finance, The John Paul II Catholic University of Lublin, Poland, email:* lgruszecki@kul.pl
[2]*Director and Associate Professor of the Institute of Economics and Finance, The John Paul II Catholic University of Lublin, Poland, email:* bjozwik@kul.pl
[3]*Associate Professor of Faculty of Economics and Business Management, National University of Laos, Lao People's Democratic Republic,*
email: phouphetkyophilavong@gmail.com

1. Introduction

The concept of the environmental Kuznets curve got spread at the beginning of the 1990s, mainly by the World Bank, which in 1992 published a report entitled "Development and the Environment." That concept also appeared in the works by Grossman and Krueger (1991; 1995), Shafik and Bandyopadhyay (1992), Selden, and Song (1994), as well as Holtz-Eakin and Selden (1995). It refers to the notion of the Kuznets curve from the middle of the 1950s, which shows the relations between income inequalities and economic development (Kuznets, 1955). The environmental Kuznets curve, on the other hand, assumes that economic development, measured by GDP per capita, is followed by an initial increase in pollution level (i.e., a decrease in environmental quality) after which – when the so-called "turning point" is crossed, this level goes down (i.e., environmental quality increases).

Therefore, according to this hypothesis, the environmental Kuznets curve takes the shape of an inverted letter U. In the classic view, three phenomena, namely 1) determine this shape of the curve, the scale effect, 2) the technique effect, and 3) the composition effect. The first one affects the increase in pollution level that accompanies the increase in production. The 2^{nd} effect using technologies that are more favorable to the environment, contributes to decreased volume of toxic emissions and the degree of ecosystem degradation. The 3^{rd} effect also increases the quality of the environment, which takes place through a decrease of the share of energy-consuming branches of economy in GDP for the benefit of services and modern, more pro-ecological kinds of production. The phenomena do not refer, at least not directly, to the effects following from international economic relations, for example, trade, which have an increasingly greater influence on economic growth today. The present article deals with this aspect.

The article's main aim is to develop the economic model of the environmental Kuznets curve that would show the effect of international relations of economies on the aggregate pollution of the environment. This is a new view in the studies on the relations defined by the environmental Kuznets curve. The theoretical considerations present in literature mainly concern the analysis of relations in one economy's dimension only. The model presented here contributes to filling this gap and developing studies of this issue in an international view.

The article consists of the introduction, five sections, conclusions, and bibliography. The separate five sections deal successively with a review of the literature on international relations and the environmental Kuznets curve, basic concepts and assumptions for the analyzed model of two economies, a description of the dynamics of the aggregate degradation of the environment, the definition and theoretical analysis of the Home country's and Foreign country's influence on the aggregate pollution level, and description of special formulas for the environmental Kuznets curve.

2. International Relations and the Environmental Kuznets Curve

Increasing the interest of scientific circles in the environmental Kuznets curve concept clearly started at the beginning of the 1990s. Most research aim to examine the relationship between environmental degradation and economic development in a single economy. The international viewpoint appears principally in comparative studies, which examine research results in groups of countries predominately belonging to an organization or located in one region. Well-known examples of comparisons of economic development and environmental degradation in organizations include the research in the European Union countries (Pablo-Romero and Sánchez-Braza, 2017; Loures and Ferreira, 2019), in OECD countries (Lau *et al*., 2018; Dyrstad *et al.,* 2018; Churchill *et al.,* 2018), in ASEAN countries (Duan *et al*., 2016; Liu *et al.,* 2017; Kisswani *et al*., 2018), in BRICS countries (Abdouli *et al*., 2017). Regional comparisons can be found in the studies on European countries (López-Menéndez *et al*., 2014; Destek *et al*., 2018), East Asia and the Pacific region (Dong *et al.,* 2018), Southeast Asia (Wu and Wijaya, 2018), or on Latin America and the Caribbean (Hanif, 2017). In addition to the listed studies, there are also comparisons between a few regions (Europe, East Asia and the Pacific, South Asia, and South and North Americas) presented by Al-Mulali *et al*. (2016). Interestingly, there are comparative analyses in a metropolitan dimension, for example, by Fujii *et al*. (2018), who studied 276 global metropolises. As mentioned in the introduction, studies containing theoretical considerations and research results on economies' international interactions are occasionally encountered.

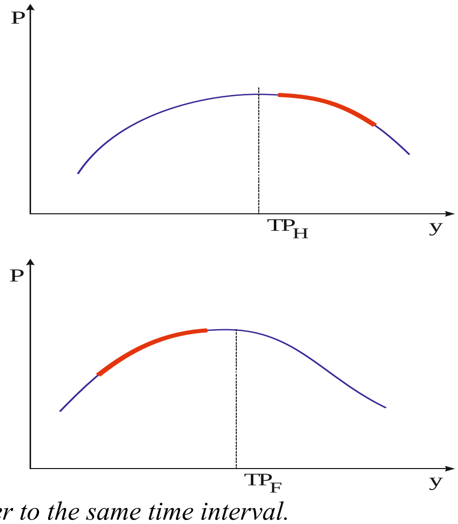
Theoretical considerations on the foreign effect on environmental degradation concern most foreign trade and the movement of capital, mainly in the form of foreign direct investments. It needs to be emphasized that in the light of empirical studies, the effect of foreign trade on the environment is not explicit, which was already pointed out in the 1990s by, among others, Jones and Rodolfo (1995), Lee and Roland-Holst (1997), and later by Dinda (2004). For instance, deterioration of the environmental quality can occur due to the scale effect caused by increased export. On the other hand, foreign trade can "positively" affect the environment through the composition effect and the technique effect. In this case, the composition effect consists of decreasing pollution-intensive goods in each country while simultaneously increasing this production abroad. The domestic demand for these goods, which does not change with the production structure's change, is satisfied by import. The composition effect relates to two hypotheses, namely the displacement hypothesis and the pollution haven hypothesis. According to the displacement hypothesis, trade liberalization leads to faster growth of production in pollution-intensive industries with fewer environmental regulations, usually less developed countries. According to the pollution haven hypothesis, heavy polluters move to countries with weaker regulations. The pollution haven hypothesis argues that low environmental standards become a comparative advantage source, thus leading to shifts in trade patterns.

The foreign direct investments flow, on the one hand, can follow from the wish to transfer economic activity to the countries with weaker environmental restrictions (pollution havens) but, on the other, it can cause a reduction in environmental pollution as a result of the technique effect (diffusion of technology) (Martin and Wheeler, 1992; Reppelin-Hill, 1999). This can occur when foreign direct investments transfer the more environmentally friendly technology, mostly from the economically developed countries to the developing ones. Studies on the relations between foreign direct investment and environmental degradation were conducted, for example, by Hitam and Borhan (2012), Ren *et al*. (2014), Abdouli and Hammami (2016), Zhu *et al*. (2016), Abdouli *et al.* (2017) and Dang (2018). Comprehensive studies analyzing high-, middle-, and low-income countries over the period 1975–2012 were published by Shahbaz *et al.* (2015). Unfortunately, the authors find out that foreign direct investment increases environmental degradation, thus confirming the pollution haven hypothesis.

3. Basic Concepts of the Model of two Economies: Home Economy and Foreign Economy

We will examine two areas with different economic policies. Following the commonly adopted terminology, the first, more developed area will be called Home Country (*Home*), while the other one – Foreign Country (*Foreign*). *Home* and *Foreign* are placed in different environmental Kuznets curves. We will examine one of the alternatives in particular, that is the situation when in a defined time interval *Home* lowers its pollution, which means that it has crossed its turning point TP_H, while *Foreign* is in the phase of development before TP_F and, therefore, in its case environmental degradation increases (Figure 1).

Figure 1. *Environmental Kuznets curves in Home and in Foreign*



Note: *Bold curves refer to the same time interval.*
Source: *Own study.*

Symbol P denotes environmental pollution, while y denotes per capita income. It should be noted that the concept of the environmental Kuznets curve itself requires clarification. We will further consider two kinds of this curve:[4]

(I) ***type I****:* curves, which represent the emissions of harmful substances or the environment quality when the pollutants undergo immediate biodegradation.

(II) ***type II:*** curves, which represent the state of pollution when the degree of degradation depends on present emissions and also on emissions from the previous period and, moreover, the pollutants undergo a low of degradation, for example exponential degradation.

At this point, it is worthwhile to refer to the results of empirical studies, which differ depending on the choice of the above-mentioned variables. Environmental degradation is defined as pollution at a given moment, for instance, in a given year (flow pollution), or as a cumulative effect of the negative impact at a longer time period (stock pollution). This distinction was pointed out in Lieb (2004), who analyzed the studies published in the years 1993-2003. Most analyses of variables at a given moment (flow pollution) pointed to the relations illustrated by the environmental Kuznets curve in the shape of an inverted U; e.g., the first published studies such as Panayiotou (1993), Selden and Song (1994), Carson *et al*. (1997), Cole (2000). A few studies pointed to the relations presented in the form of a letter N, when the scale effect overcomes the composition and technique effects, Grossman (1995), Grossman and Krueger (1995), Panayiotou (1997), Kaufmann *et al.* (1998), Torras and Boyce (1998), Dinda *et al*. (2000), Roca *et al*. (2001) and Friedl and Gletzner (2003). At present, this relation was confirmed, for example, in the publications by Bhattarai *et al.* (2009), Álvarez-Herranz and Balsalobre Lorente (2015; 2016), as well as Allard *et al*. (2018). On the other hand, in most cases, the analysis of cumulative variables (stock pollution) only pointed to a monotonic increase in time pollution.

4. Dynamics of Aggregate Environmental Degradation

We will examine the dynamics of aggregate pollution generated by *Home (H)* and by *Foreign (F)*. Let us denote for curves of the above two types

$$P_i(t) = EKC_i\big(y_i(t)\big), \quad i = H, F, \tag{1}$$

where indices H and F refer to the environmental and per capita income curves of *Home* and *Foreign* respectively, while time $t \geq 0$.

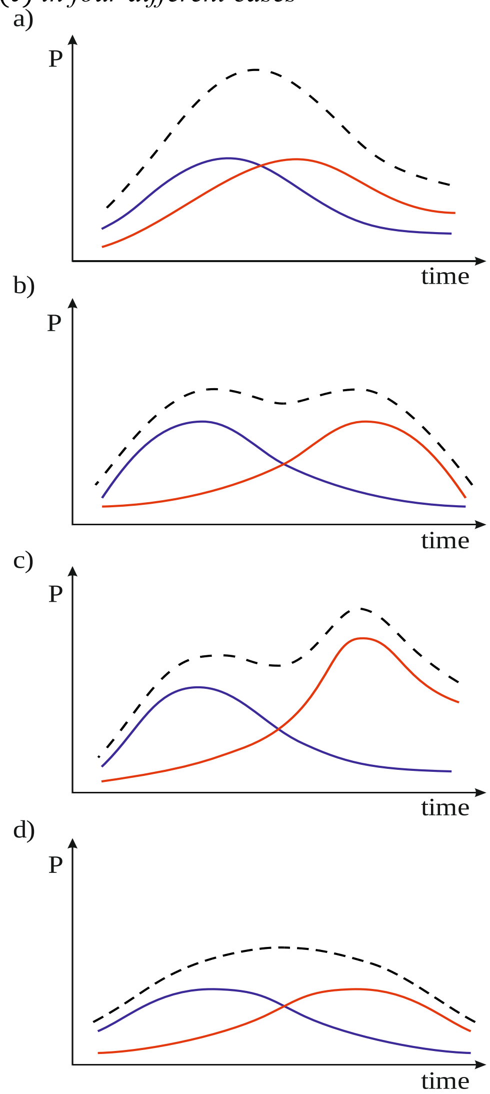
[4] *This distinction is drawn attention to by, for example, Lopez (1994), who – however – does not use the symbols presented here.*

Aggregate pollution at a moment *t* is defined as the sum of pollution in *Home* and in *Foreign*.

$$P(t) = P_H(t) + P_F(t). \tag{2}$$

Function $\mathrm{P}(t)$ may have different shapes with one or more than one maximum depending on the lag in development between *Home* and *Foreign*, internal dynamics of development of both economies, and their economic potentials (Figure 2).

Figure 2. *Curve* $P(t)$ *in four different cases*



Note: *Dotted line marks aggregate pollution.*
Source: *Own study.*

In Figure 2, the pollution curve P_F (t) of Foreign's economy, which is less developed than Home's economy, is shifted to the right concerning P_H (t). In graph a), the potentials of both economies are similar, and the shift is relatively insignificant, which should be interpreted as a relatively small lag in development; the lines intersect for pollution values close to the maximum levels of these economies, which gives the aggregate pollution curve with one maximum. Graph b) shows the curves that correspond to a significant lag of Foreign about Home, with two countries having similar economic potential. In this case, the aggregate pollution curve has two maximum pollution levels of similar values. Graph c) shows a considerable development lag of Foreign, which has significantly greater economic potential; this leads to two local maxima in the curve P(t), the second of which is associated with significantly greater aggregate pollution. Graph d) shows two flat pollution curves; their maxima are quite far apart on the time axis, which indicates a significant development lag of Foreign about Home. However, such shapes of P_H (t) and P_F (t), which reflect low dynamics of change, mean that there is only one maximum aggregate pollution level.

As can be easily seen, if the derivative $P'(t) > 0$, then the aggregate pollution increases, if however $P'(t) < 0$, the aggregate pollution decreases, and equality $P'(t) = 0$ is the necessary condition for the maximum (as well as minimum) of local pollution.

Now we will consider the following assumption:

(Assumption A)	*Home's economy is in the phase of lowering pollution, while less developed Foreign increases its pollution.*

With the above assumption, we have the following implications:

If

$$\frac{EKC_H'(y_H(t))}{EKC_F'(y_F(t))} > -\frac{y'_F(t)}{y'_H(t)},$$

that is, if the ratio of the rate of change in pollution levels in *Home* and *Foreign* is greater than the ratio of the rate of change in per capita income of *Home* and *Foreign*, with the minus sign, then the aggregate pollution increases; if the inequality is the other way, the pollution decreases.

In a particular case when t_0 is the moment in time when the aggregate pollution reaches maximum, the above-mentioned ratios of the rate of change in pollution level and increase in per capita income, with the minus sign, will be equal

$$\frac{EKC_H'(y_H(t_0))}{EKC_F'(y_F(t_0))} = -\frac{y'_F(t_0)}{y'_H(t_0)}. \tag{3}$$

Condition (3) is also sufficient if the derivative $P'(t)$ changes the sign in the neighborhood of t_0 (or the second derivative $P''(t_0) < 0$).

Equality (3) can also be written as

$$\frac{P_H{}'(y_{H0})}{P_F{}'(y_{F0})} = -\frac{y_F'(t_0)}{y_H'(t_0)}, \tag{4}$$

where $y_{i0} = y_i(t_0)$.

Let us note that if **(A)** is assumed, $P_H{}'(y_{H0}) < 0$ and consequently, equality (4) means that at an extreme point the ratio of the rate of change in pollution levels in *Home* and *Foreign* is inversely proportional to the ratio of the rate of increase in per capita income in *Foreign* and *Home*. At the same time, if the first ratio is greater than the second one, the aggregate pollution increases, whereas if it is smaller, the aggregate pollution decreases.

The above conditions can be given a different form when we refer to the concepts of elasticity:

$$\varepsilon_{EKC_i, y_i} \ , i = H, F, \tag{5}$$

and

$$\varepsilon_{y_F, y_H}. \tag{6}$$

Simple calculations give the equation equivalent to (3) and (4), namely

$$\frac{EKC_H}{EKC_F} = -\frac{\varepsilon_{EKC_F, y_F}\varepsilon_{y_F, y_H}}{\varepsilon_{EKC_H, y_H}}, \tag{7}$$

where the values on the left and right side correspond to extreme values y_{H0} and y_{F0}.

Thus, if the aggregate pollution reaches extreme values, then the ratio of pollution levels in *Home* and *Foreign* is equal to the ratio (with the minus sign) of elasticity of pollution levels in relation to per capita income in *Foreign* to the corresponding elasticity calculated for *Home*, multiplied by the elasticity of per capita income of *Foreign* in relation to per capita income in *Home*.

Obviously, if

$$\frac{EKC_H}{EKC_F} > -\frac{\varepsilon_{EKC_F, y_F}\varepsilon_{y_F, y_H}}{\varepsilon_{EKC_H, y_H}}$$

then the aggregate pollution increases, whereas if the inequality is reversed – the aggregate pollution decreases.

5. Influence of Home and Foreign on the Aggregate Pollution

To determine the effect of mutual interaction between Home and Foreign, let us use the Keynesian model. In the model, we assume that Home's income depends on exports. We also assume that both Home and Foreign are large economies that are interdependent. For example, if a Foreign' s income increases, foreigners import more from the Home country, increasing its income. Thus, Foreign economic growth is transferred through the trade balance to Home. Similarly, a decline in economic activity is transferred. Thus, an important assumption is made in the Keynesian model:

(Assumption B)	$\Delta Y_F = \frac{m_H}{s_F+m_F}\Delta Y_H$

where Y_F, Y_H denote *Foreign's* and *Home's* national incomes, m_H and m_F denote the marginal propensity to import of both economies, and s_F denotes *Foreign's* marginal propensity to save. Let us note that condition b) is significantly limiting, since it is assumed that the economic growth of *Foreign* depends only on the growth transferred through trade.

If N_H and N_F denote populations of *Home* and *Foreign*, which are constant in a given period of time, then

$$\frac{\Delta Y_F}{N_F}N_F = \frac{m_H}{s_F + m_F}\frac{\Delta Y_H}{N_H}N_H,$$

or

$$\Delta y_F = \frac{km_H}{s_F + m_F}\Delta y_H,$$

where $k = N_H/N_F$ is the population ratio of both economies. Hence:

$$y'_F(t) = \frac{km_H}{s_F+m_F}y'_H(t). \tag{8}$$

This means that the growth rate of per capita income in *Foreign* is proportional to the growth rate of per capita income in *Home*, and the proportionality coefficient depends on the population ratio in both countries (economies), their marginal propensities to import and the marginal propensity to save of the Foreign country.

Substituting (8) into (3), we get:

$$\frac{EKC_H{}'(y_H(t_0))}{EKC_F{}'(y_F(t_0))} = -\frac{km_H}{s_F+m_F} \tag{9}$$

which describes the extreme points (in particular the maximum) of the aggregate pollution function. At these points, the ratio of the rate of pollution decrease in *Foreign* is equal to the proportionality coefficient. At the same time, the following implication holds:

if

$$\frac{EKC_H{}'(y_H(t))}{EKC_F{}'(y_F(t))} > -\frac{km_H}{s_F+m_F}, \tag{10}$$

then the aggregate pollution increases. Otherwise, if the inequality is reversed, the aggregate pollution decreases.

Since the elasticity of per capita income in *Foreign* in relation to per capita income in *Home* is directly proportional to the quotient of *Home's* and *Foreign's* incomes, i.e.:

$$\varepsilon_{y_F,y_H} = \frac{km_H}{s_F+m_F}\frac{y_H}{y_F}, \tag{11}$$

then, considering (7) and (11),

$$\frac{EKC_F}{EKC_H} = -\frac{(s_F+m_F)y_F\varepsilon_{EKC_H,y_H}}{km_H y_H \varepsilon_{EKC_F,y_F}}. \tag{12}$$

Equality (12) allows us to calculate Home's and Foreign's proportional contribution to the aggregate pollution when the pollution level reaches extreme values. The ratio of Home's and Foreign's contribution to the aggregate pollution is, in this case, directly proportional to the ratio of per capita income in Home and Foreign, as well as directly proportional to the ratio of elasticity of pollution levels about Home's and Foreign's national incomes. It should be noted that the change in the elasticity of the pollution level about Home's and Foreign's national incomes, which affects the aggregate pollution, may result from a few factors:

1. Income growth often increases consumer demand for better environmental quality and the public sector's involvement to improve this quality.
2. In higher-income countries, the public is more aware of the need to protect the environment; this awareness is connected with a well-developed

education system.

3. A rise in income is usually followed by structural changes in the economy, including changes into environmentally friendly technologies (Shahbaz, Sinha 2018).

The described relationships are reflected in models of the environmental Kuznets curve derived from microeconomics, in which demand has an important influence on environmental quality. It is worth mentioning that this relationship's simple statistical models were first presented by McConnel (1997), among others. He was followed by Andreoni and Levinson (2001), to name a few. Equation (12) allows to predict the aggregate level of pollution corresponding to extreme values of per capita income, namely

$$P_{max} = max\left\{EKC_H(1 - \frac{(s_F+m_F)y_F\varepsilon_{EKC_H,y_H}}{km_H y_H \varepsilon_{EKC_F,y_F}})\right\}, \tag{13}$$

where the maximum includes all extreme values; the symbol "max" may be omitted if, on the basis of economic analysis, it can be stated that $P(t)$ has one local maximum which is at the same time its global maximum.

In conclusion, it should be emphasized that the aggregate pollution generated by both economies is not a simple sum of pollution generated by these economies treated in isolation. International economic relations result in a faster growth of a less developed country, and consequently have an influence on the degradation of its environment. As a result, the turning point is crossed faster, which translates into the aggregate pollution.

6. Special Formulas for the Environmental Kuznets Curve

Let us propose special formulas for the curves of types I and II. These formulas characterize environmental destruction by activities characterized by different time dynamics. In the present considerations, dependence on time is of significant importance. At first, we will assume that per capita income increases in time; next we will show how to omit this assumption. We will define the curve of type I by

$$EKC^{(0)}\big(y(t)\big) = em(t), \tag{14}$$

where $t \longmapsto em(t)$ is an emission function, whereas the other curve (type II) will be defined by the following formula:

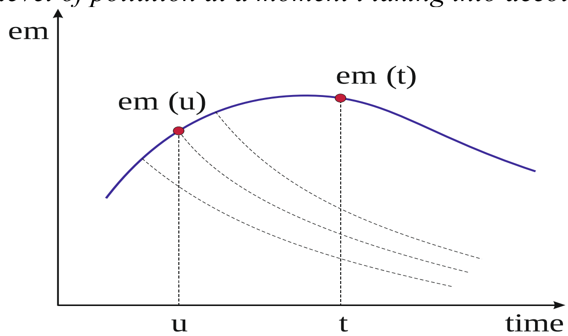
$$EKC^{(b)}\big(y(t)\big) = em(t) + e^{-bt}\int_0^t em(u)e^{bu}du, \quad b > 0. \tag{15}$$

It should be noted that we consider not one curve, but a family of curves $EKC^{(b)}, b > 0$; each case for specific $b > 0$ is connected to the special case of polluting substance. Thus, b is treated as fixed when we consider particular curve. Apart from this, we have to note that the case $b = 0$ is not the limit of the case $b > 0$ as $b \longrightarrow 0^+$. Curves of the first type emerge from different methodology of investigating the problem of pollution than curves of the second type. The two approaches presented above can be found in the literature.

Let us note that curves (15) may belong to type II but in fact this formula without additional assumptions is more general than that type, because it describes cases dependent not only on $y(t)$ but also, and independently, on time t.

The above formulas point to a relation between the pollution level at a moment of time t and the level of emissions (e.g. CO_2 emissions). This level is defined by the environmental Kuznets curves of type I (upper line) and type II (lower line). For type I curves, the value $EKC^{(0)}(y(t))$ is directly determined by the volume of emissions at a given moment. In the case of type II curves, the value $EKC^{(b)}(y(t))$, $b>0$ is calculated is calculated by summing up the effect of all emissions from the preceding period. This situation is illustrated in Fig. 3. below. Value t on the time axis is represented by the points that show the contribution of pollution generated in the earlier period to the pollution level at this time. For example, for emissions, $u<t$, this contribution equals $em(u)e^{-b(t-u)}$. The dashed lines show a gradual bio-degradation of toxic emissions with the passage of time.

Figure 3. *Real level of pollution at a moment t taking into account earlier emissions*



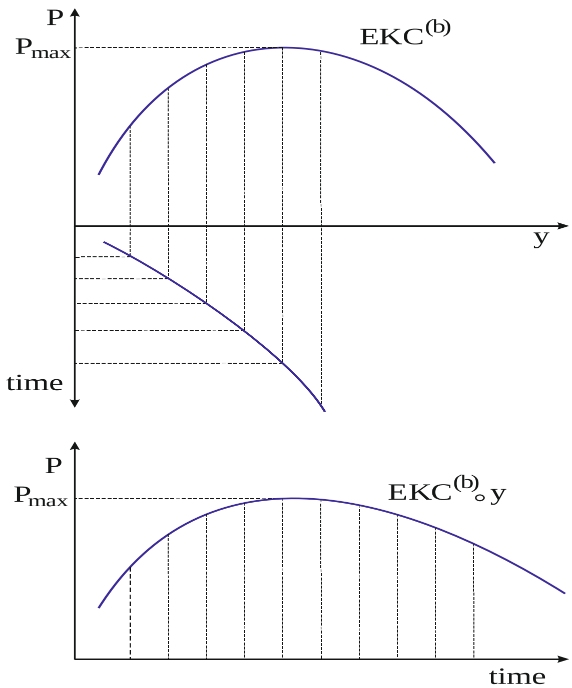
Source: *Own study.*

Next, we will discuss two cases: $b = 0$ and $b > 0$ which, for convenience, will be treated as one $b \geq 0$, when it is possible. Let us note that function[5]: $EKC^{(b)} \circ$

[5]*Symbol* $EKC^{(b)} \circ y$ *is used here to mark the curve which arises from the environmental Kuznets curve though the "re-scaling" of variable y by means of function y=*$y(t)$*. Hence,* $EKC^{(b)}$ $(y(t))$ *is the time course of the Kuznets curve.*

$y(t)$=$EKC^{(b)}(y(t))$ keeps certain properties of the Kuznets curve $EKC^{(b)}(y)$. The curve which is a graph of $EKC^{(b)}(y(t))$ also first increases and then decreases sharply when $y(t)$ grows fast, or less sharply when $y(t)$ grows more slowly. Function $EKC^{(b)} \circ y$ increases very slowly in the initial period of development of a given economy and this is due to the slow growth of y (empirical studies on this initial period are generally limited). Next, a period of fast growth of per capita income takes place, which is illustrated by a fast climb on the environmental Kuznets curve and hence the slope of $EKC^{(b)} \circ y$ is steeper than that of $EKC^{(b)}$ for the corresponding values of per capita income. Then the income increase slows down and, consequently, the graph of relevant fragments of $EKC^{(b)} \circ y$ is flattened.

Figure 4. *$EKC^{(b)}$ and per capita income curves (on the left) and $EKC^{(b)} \circ y$ (on the right)*



Source: *Own study.*

It should also be noted that the time parameter is not a "causal" variable, but just an element of a dynamic description of y and P. If $b = 0$, the relationship between the volume of emissions at a given time and the pollution level is obvious. If $b > 0$, as can be easily seen, differentiating the following formula

$$e^{bt}EKC^{(b)}(y(t)) = e^{bt}em(t) + \int_0^t em(u)e^{bu}du$$

leads to the first order differential equation

$$em'(t) + (b+1)em(t) = bEKC^{(b)}\big(y(t)\big) + EKC^{(b)'}\big(y(t)\big) \cdot y'(t).$$

Therefore,

$$em(t) = e^{-(b+1)t}\Big(\int q(t)e^{(b+1)}dt + C\Big),$$

where $q(t) = bEKC^{(b)}\big(y(t)\big) + EKC^{(b)'}(y(t)) \cdot y'(t)$; constant C may be calculated based on initial condition $em(t_0) = em_0$, which we can establish empirically.

The formula above allows to calculate the level of emissions that results in the degradation level determined by the environmental Kuznets curve at time *t*.

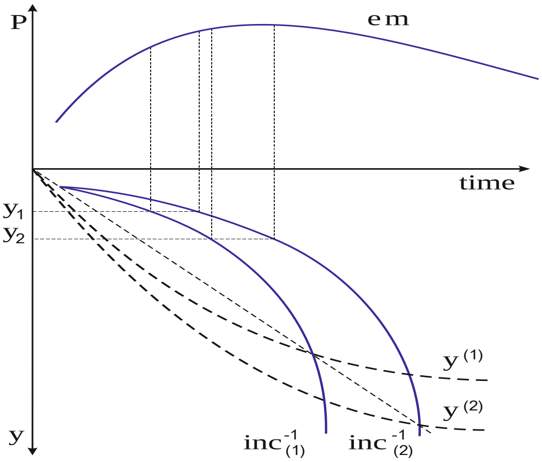
If per capita income increases in time, then:

$$EKC^{(b)}(y) = \begin{cases} em(inc^{-1}(y)) & for\ \ b = 0, \\ em(inc^{-1}(y)) + e^{-binc^{-1}(y)} \int_0^{inc^{-1}(y)} em(u)e^{bu}\, du & for\ \ b > 0, \end{cases}$$

(16)

where inc^{-1} denotes a function that is inverse to $y(t)$. The relationship presented above for $b = 0$ can be illustrated by the Figure 5.

Figure 5. *The speed of pollution changes for two different functions of per capita income increase*



Source: *Own study.*

Symbols $y^{(1)}$ and $y^{(2)}$ denote two different (hypothetical) per capita income functions. The dashed lines show the courses of functions over time. Symbols $inc_{(1)}^{-1}$ and $inc_{(2)}^{-1}$ denote relationships inverse to $y^{(1)}$ and $y^{(2)}$, respectively. Their graphs are marked with solid lines. Figure 5. shows how emission levels change when per capita income changes from value $y^{(1)}$ and $y^{(2)}$ in the two functions of income per capita. Namely, for the income function $y^{(1)}$ that represents a less developed economy, emissions of toxic substances take the levels that were previously reached by a more developed economy. At the same time, emission levels depend on changes in per capita income. (The parameter *t* is in fact eliminated, which is connected with viewing the environmental Kuznets curve as the relationship between environmental degradation and per capita income, not taking into account dependence on time).

As can be seen, a faster increase in income results in a faster movement of emissions along the curve. Thus, a dynamically developing economy moves faster from the pollution increase phase to the stabilization, and then to the decrease phase. The situation is similar when $b > 0$.

If the emission curve is in the shape of an inverted *U*, then the Kuznets environmental curve is also of a similar shape, with the turning point $TP = y(t_{TP})$ where t_{TP} is a turning point on the time axis and:

1) for $b = 0$, $em'(t_{TP}) = 0$,
2) for $b > 0$, $em(t_{TP}) + em'(t_{TP}) = be^{-bt_{TP}} \int_0^{t_{TP}} em(u)e^{bu}du.$

The first equality follows from the fact that for $b = 0$, the maximum of the environmental Kuznets curve is causally related to the current emission level. In the second case, the situation is more complicated due to the persistent impact of emissions from the previous period; the condition obtained is a consequence of equating the derivative of $EKC^{(b)} \circ y(t), b > 0$ to zero.

We can apply formulas (14) and (15) to general equality (3). We get

$$\frac{EKC_F^{(0)}{}'(y(t_0))^2}{EKC_H^{(0)}{}'(y(t_0))^2} = -\frac{em'_F(t_0)}{em'_H(t_0)} \tag{17}$$

for curves of the first type, and

$$\frac{EKC_F^{(b)}{}'(y(t_0))^2}{EKC_H^{(b)}{}'(y(t_0))^2} = -\frac{em'_F(t_0)+em_F(t_0)-b\int_0^{t_0} em_F(u)e^{bu}du}{em'_H(t_0)+em_H(t_0)-b\int_0^{t_0} em_H(u)e^{bu}du} \tag{18}$$

for curves of the second type which have the form of (15). Analogously, we can apply formulas (14) and (15) to equality (9), which shows the relation between *Home* and *Foreign* in the Keynesian theory.

Up till now we have assumed that $y(t)$ increases in time. In fact, in some models we accept such behavior of per capita income. However, it is generally accepted that the economy grows cyclically. Thus, the function $inc^{-1}(\{y\})$, for some y, may include several time values.

A way out of this situation is to consider the trend function $y_{TR}(t)$ in place of $y(t)$. The trend function shows the growth of per capita income, disregarding short-term declines in income caused by recessions. Then, the relationships between the pollution level and time parameter, and per capita income should be treated as approximate.

Hence,

$$EKC^{(b)}(y_{TR}(t)) \approx f^{(b)}(t),$$

where $f^{(b)}(t)$ denotes the right side of (14) and (15) for $b = 0$ and $b > 0$ respectively. Obviously, the assumption that $y_{TR}(t)$ increases in time, fits into the broad framework of the theory of sustainable growth. The above approximate equality leads to

$$EKC^{(b)}(y_{TR}) = f^{(b)}\big(inc^{-1}(y_{TR})\big), b \geq 0,$$

which approximates the formula for the environmental Kuznets curve. This approximation largely eliminates the problem connected with the assumption that per capita income increases permanently over time, thus making it possible to include in formulas (14) and (15) also those cases where per capita income decreases, for example during economic crises.

7. Conclusions

This article develops the economic model of the environmental Kuznets curve that shows the effect of economies' international relations on the aggregate pollution of the environment. It is assumed that the impact on aggregate environmental pollution depends on the trade exchange, which directly influences both countries' economic growth (this assumption refers to the Keynesian model). In our economic model, the trade exchange results in increased growth of both countries, affecting the degradation of their environment, with the perspective of the turning point being crossed faster in a less developed country (Foreign).

This is a new point of view in the literature on the subject. Theoretical considerations and empirical research concerning the environmental Kuznets curve have been mostly focused on one economy. The international perspective in those studies has been adopted less frequently. If it has, these are first comparisons of study results in countries belonging, for example, to an organization or situated in a given region. The general recommendations that can be formulated based on the model on reducing pollution from emissions in developing countries, where the turning point has not been crossed, include, among others, influencing the income elasticity of demand for the environmental quality. This can be done by increasing the effect of economic policies aimed at supporting structural changes in the economy, which is connected with changing technologies into more environmentally friendly ones, getting the public sector more involved in environmental protection, and raising the social awareness of the necessity to protect the environment; e.g., through supporting education and scientific research in this field.

Finally, we would like to draw attention to developing studies into the relations between economic development and environmental degradation from an international perspective. Such an approach in today's economic policy is necessary due to globalization and the resulting intensification of international economic relations. Hence, it seems to be necessary to intensify international coordination of national environmental protection policies.

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