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# Economic Growth and Transnational Pollution Transfer: Verification of the Trading Environmental Kuznets Curve Hypothesis

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## Abstract

With the economic globalization and the development of various countries, transnational pollution transfer has become a common phenomenon and is increasingly being monitored by the international community. This paper uses the fixed-effects regression model and the balanced panel data of 50 countries from 1990 to 2016, innovatively proposes the Trading Environmental Kuznets Curve (TEKC) and empirically tests it from the perspective of the difference between ecological footprint's import and export, and explains the internal mechanism of the TEKC. The results demonstrate a U-shaped relationship between per capita GDP and the outward pollution transfer amount in pollution transferring countries. The scale effect prevents outward pollution transfer, whereas the structural and technological effects promote it. In pollution-transferred countries, the relationship between per capita GDP and inward pollution transfer amount was inverted U-shaped. The scale effect encourages inward pollution transfer, whereas the structural and technological effects inhibit it. The results of this study confirm that "pollution havens" are universal worldwide and reflect the nonlinear change of pollution transfer amounts under the influence of economic development. The conclusion of this paper is an extensibility verification of the Environmental Kuznets Curve (EKC) in the field of transnational pollution transfer.

## Keywords

Per capita GDP; outward pollution transfers; inward pollution transfers; scale effect; structural effect; technological effect

## 1. Introduction

The relationship between environmental pollution and economic growth has always been the focus of attention worldwide. With the economic globalization and the development of various countries, environmental pollution is progressively affecting the survival and development of human society. Undoubtedly, it remains one of the great challenges for every country in the world to tackle environmental pollution on the premise of maintaining economic development. Grossman and Krueger (1992) proposed that economic development of one country or region would lead to its pollution emissions rising in the beginning phase, then the emissions would gradually decrease with economic growth after reaching the inflection point, which showed an inverted "U" curve relationship, namely the Environmental Kuznets Curve (EKC). Undeniably, in developed countries, a higher income level normally means more consumption of products, which correspondingly causes much more pollution emissions, which is inconsistent with these countries' efforts to improve the environment. Where does the pollution from producing these consumer goods go? Currently, disputes exist in academic circles about whether environmental improvement is achieved through endogenous means (domestic) or by transferring polluting production to other relatively backward countries (Pollution Haven Hypothesis) (Aklin, 2016). In reality, it is difficult for a country to reduce emissions entirely through domestic environmental regulation and green technology (Gamso, 2017). With the increasing attention paid to environmental quality in some high-income countries, their environmental regulations have been continuously upgraded, forcing their own polluting industries to be transferred to low-income countries with relatively loose environmental regulations (Fang et al., 2021), and then importing polluting products from those low-income countries instead of self-production for domestic consumption (Li et al., 2021). In order to develop the domestic economy, low-income countries had to introduce polluting industries transferred from high-income countries at the expense of the domestic environment (Liu et al., 2021).

This paper introduces the ecological footprint (EF), a comprehensive environmental index proposed by Rees (1992) to better measure the cumulative pollution of a country on air, land, and water. The pollution caused by a country's production activities will consume a certain amount of EF. When the country begins to reduce some products' manufacturing and fill the gaps by importing the same products with implied ecological footprints, which means transferring the pollution to other countries, it inevitably makes those countries "pollution havens" (Chung, 2014). Previous studies on the relationship between economic development and pollution transfer have the following shortcomings: For starters, EKC is typically used to examine the impact of economic level on local pollution emissions, which does not explain the relationship between economic development and transnational pollution transfer. "Pollution Has Hypothesis" (PHH) only answers the transfer direction of pollution (Tang, 2015). The transferred pollution amount with economic growth has not been replied positively. Thirdly, most studies did not consider the heterogeneity in the direction of pollution transfer; that is, the research samples were not divided into pollution transferring countries and pollution transferred countries for targeted research.

In view of the above limitations, the new concept, TEKC, is introduced in this paper.

From the perspective of the trade surplus and deficit of the ecological footprint, the countries whose ecological footprint import is greater than (less than) export each year are regarded as pollution transferring (transferred) countries. The nonlinear relationship between pollution transfer amount and economic growth of various countries is verified by using the fixed effect regression mode, and the internal mechanism of pollution transfer is analyzed from the scale, structure, and technical effect. Through empirical research, the gap in the field of pollution transfer and economic growth is filled, the study of EKC is expanded, and a theoretical basis is proposed for sustainable development in these countries.

## 2. Literature review

The Kuznets Curve was proposed by Simon Smith Kuznets in 1955, which revealed the inverted U-shaped curve relationship between income inequality and economic development. Then, Grossman and Krueger (1992) proposed the EKC, which investigated that the relationship between pollutant discharge and per capita GDP fulfilled the inverted U-type curve. Panayotou (1997) found that government policies as an additional factor on EKC could effectively curb the pollution emissions caused by economic development. Antweiler et al. (2001) conducted empirical research on EKC by introducing scale effects, structural and technical effects, which better explained the formation mechanism of EKC and enriched the theoretical interpretation of EKC.

It has long been attracting academic attention to validate the existence of an EKC. Some scholars have empirically tested whether the EKC existed in a region and studied the impact of foreign direct investment on carbon emissions (Mahmood et al., 2020). Instead of selecting the traditional EKC curve's carbon emission indicators, Ulucak and Bilgili (2018) used domestic ecological footprint consumption to represent pollution emissions and found the EKC's existence in high-, medium-, and low-income countries. Other scholars have also confirmed the existence of EKC and found the significant impacts of population, industrialization, urbanization, and government regulations on pollution emissions.

However, EKC has contrarily been questioned by some other scholars, which is mainly embodied in the three viewpoints below. Firstly, Yilanci and Pata (2020) have proved the ecological footprint trajectory's monotonous increasing form in terms of Chinese provincial data, rather than the inverted U-type curve described by the traditional EKC hypothesis. Secondly, Zhang and Ren (2011) have investigated the N-type relationship between pollution emissions and economic development in China. Thirdly, Pata and Caglar (2021) have brought out a U-type relationship between pollution emissions and economic development level.

EKC has been expanded to different fields in recent years. Muhammad et al. (2020) revealed an inverted U-type relationship between carbon dioxide emissions and urbanization. Katircioğlu (2014) found that the development of Singapore's tourism industry was also in line with EKC, and tested an inverted U-shaped relationship between traffic safety and economic growth by using the Kuznets Curve in the field of transportation.

From the above literature, the traditional EKC has been limited to describing the link between pollution emissions and the level of economic development within one region, and it has failed to explain the pollution transfer across countries. Given all that, this paper expansively proposes the TEKC to further explain the relationship between cross-country pollution transfer and economic growth.

## 3. Theoretical hypothesis

By grouping the data collected from 1990 to 2016, countries whose annual ecological footprint imports are greater than exports are regarded as pollution-transferring countries, and countries whose ecological footprint exports are greater than imports are regarded as pollution-transferring countries. With the guidance of the theory of factor endowment, it is found that pollution-transferring countries generally have higher per capita income and poorer natural resources than Japan. Due to the more advanced industrial foundation and technical level, these countries have lower ecological footprint exports. Their industrial materials are more dependent on imports, and their products are mostly technology-intensive and export-oriented. Accordingly, the ecological footprint of imports from these countries has been greater than that of exports from 1990 to 2016. On the contrary, those pollution-transmitted countries have uncompleted industrial and low technical levels, even in the primary stage like Indonesia, although their reserves of natural resources are abundant. The continuous exploitation and processing of raw materials and energy products has worsened their domestic environment, and then such immature industrial structures make these countries become "pollution havens." This paper will be based on the analysis of pollution transfer between the two different groups of countries.

### 3.1. Outward pollution transferring countries

The outward pollution transfer amount from pollution transferring countries shows a "U" relationship with economic development. In detail, these countries exported much more EF but imported less EF in the early stages of economic development due to a large proportion of capital-intensive and pollution-intensive industries. The export of EF would gradually increase with economic growth, which resulted in EF's trade deficit shrinking, which meant that the outward pollution transfer amount would be reduced. With the economy growing to a certain level, their industrial structures gradually turned to be technology-intensive and service-intensive, which gradually decreased the export of EF and the EF trade deficit increased. That is, the outward pollution transfer amount has increased. In order to better explain this "U" relationship, the following analysis will be carried out from the perspectives of scale effect, structure effect, and technology effect.

The scale effect mainly inhibits the outward pollution transfer amount in the initial stage of economic development in pollution-transferring countries. These countries' industries were often at the lower end of the global value chain in the early stages of economic development. With their economic development and industrial scale expansion, the EF consumed by production also increases. These parts of goods produced by the EF consumed were exported to other countries, which aggravated domestic environmental pollution and shrank the EF trade deficit. That is, the outward pollution transfer amount decreased.

When compared to the scale effect, the structural and technical effects promote the amount of outward pollution transfer. In their less developed stage, capital-intensive industries and heavy pollution industries were usually taken as the leading industries. With their economy's gradual improvement, the portion of labor-intensive industries gradually shifted to capital-intensive industries, thus aggravating domestic pollution. When their economy grew to a certain high level, their industrial technology would significantly improve. It was time to transfer some of the eliminated heavy polluting industries and overcapacity industries to other underdeveloped countries, and then adjust their own industrial structure accordingly, the remaining industries would mainly be technology-intensive and service-intensive industries. With the industrial structure adjustment and technology upgrading, the EF consumed by domestic production constantly decreased. The EF export also decreased. That is, the outward pollution transfer amount increased. Therefore, the structural effect and technical effect promote outward pollution transfer, especially in the middle and late stages of economic development.

According to the above theoretical analysis, the U-shaped relationship in pollution-transferring countries is plotted. Due to scale effect, structural effect, and technical effect, which play inhibitory or promotion roles in different development stages, the curve shows a "U" relationship between the outward pollution transfer amount and economic development. In summary, hypothesis is proposed as,

***H1: For pollution transferring countries, the scale effect restrains the outward pollution transfer amount; the structural effect and technical effect promote the outward pollution transfer amount. Combining these three effects, the outward pollution transfer amount has a "U" relationship with the economic development level.***

### 3.2. Inward pollution transferred countries

The inward pollution transfer amount in pollution transferred countries shows an inverted "U" relationship with economic development. Most of these countries were low-income countries. In order to develop their economies, these countries consumed a large amount of EF at the expense of environmental damage (Le et al., 2016). The increase in exports of EF results in a greater trade surplus of EF, that is, the inward pollution transfers amount increases. With economic development up to a certain high level, some higher-income countries among them began to attach great importance to the environment and formulated more environmental regulations to restrain the emissions of polluting industries (Pan & Tang, 2021). Thus, the consumption and export of EF are reduced, the import of EF is increased, and thus the inward pollution transfer amount decreases. Therefore, the inward pollution transfer amount in these countries increases earlier and decreases later with economic growth, showing an inverted "U" shape relationship. Then, similar analysis will be presented as follows for these countries from the perspective of the three effects.

Scale effects play a dominant role in the early stage of economic development. In order to better develop their economies, pollution-transferred countries took advantage of their resource endowment to develop the exploitation of energy and mineral resources, which made the scale of pollution-intensive industries expand continuously. Meanwhile, the rapid growth of capital-intensive industries also resulted in the increasing consumption and export of their EF, which promoted them to become "pollution havens". Therefore, the scale effect is a prime driving force for inward pollution transfer amounts to increase, especially in the early stages of economic development.

Structural and technical effects play a key role in the middle and late stages of economic development. From the perspective of structural effects, the role of the industrial structure was less important in the early stage of economic development. Inevitably, the industrial structure has gradually been adjusted with economic development, which improved the domestic environmental quality accordingly. The green upgrading and emission reduction of polluting industries have been encouraged (Yu & Wang, 2021). Stricter environmental regulations have also been enacted to reduce emissions from production in polluting industries, which eventually upgrade the industrial structure and lower the consumption and export of EF, thus effectively decreasing the inward pollution transfer amount. Grossman and Krueger (1992) and Antweiler et al. (2001) believe that the improvement of technology effects could benefit the domestic environmental quality in two ways: on the one hand, with technical progress, parts of domestic pollution-intensive industries and capital-intensive industries would be replaced by technology-intensive industries, which would gradually reduce the export of EF; on the other hand, with green technology innovation in pollution-transferred countries, the unit pollution emission caused by the production of pollutant products would decline, which would indirectly reduce the consumption and export of EF. Therefore, the structural effect and technical effect have an inhibitory effect on the inward pollution transfer amount in polluted countries in the middle and late stages of economic development.

According to the above theoretical analysis, the inverted "U" shape relationship in pollution transferred countries is plotted. Due to scale effect, structural effect, and technical effect, respectively, playing promotion or inhibitory roles in different development stages, the curve shows an inverted "U" relationship between the inward pollution transfer amount and economic development. Therefore, hypothesis 2 is proposed as,

***H2: With the economic development, the scale effect increases the inward pollution transfer amount; the structural effect and technical effect reduce the inward pollution transfer amount. Combining the three effects, the inward pollution transfer amount and the economic development level present an inverted "U" relationship.***

## 4. Research methods

### 4.1. Data sources and variables

The data collected in this paper is from 1990 to 2016 because of the lack of other years' data. The samples are grouped according to the sign of the export minus the import of EF. On the contrary, only those countries which have gotten a plus sign every year during this period are defined as outward pollution transferring countries, while the other countries are defined as inward pollution transferring countries. Besides, in order to target pure pollution, transfer countries, the countries that have both plus and minus signs during this period are eliminated. Thus, 39 pollution transferring countries and 11 pollution transferring countries are obtained as the investigated samples. An empirical study was conducted to verify the above proposed hypothesis according to balanced panel data from 1990 to 2016. The variables presented in this paper are as follows(Table 1):

**Dependent variables:** Ecological footprint (EF) refers to the geographical space with biological productivity that can continuously provide resources or absorb waste, which is also a kind of "carrying capacity" with which every country can more or less maintain its own ecosystem. The amounts of natural resources occupied and destroyed by various human activities will also be expressed by ecological footprint (EF) consumption data. The EF consumption data and the EF import & export volume of countries around the world have been released by the Global Footprint Network (GFN) through calculation. In general, the industries produce goods for the consumption of residents, but the production will cause environmental damage and consume some environmental footprint. In the extreme cases, when the ecological footprint of an area is exhausted, it will no longer be suitable for human habitation. When a country produces fewer pollutants than it consumes and imports more pollutants than it exports, it will consume the ecological footprint of other countries and shift the burden of pollution to other countries (EF (Consumption) -EF (Production) =EF (Import) −EF (Export)). Therefore, the countries whose EF imports more than exports actually transfer out their own pollution to others by occupying their EF, meaning that they are forced to accept the pollution transfer. In this paper, DEF is used to represent the amount of pollution transferred out from EF trade deficit countries (outward pollution transferring countries), while SUR is used to represent the amount of pollution transferred into EF trade surplus countries (inward pollution transferred countries), namely DEF = (EF import amount - EF export amount) / (EF export amount + EF import amount); SUR = (EF export amount - EF import amount) / (EF export amount + EF import amount).

**Independent variables:** Y stands for per capita GDP to measure the country's economic development level, referring to Grossman and Krueger (1992). Y2 is taken to test and verify whether the relationship between Y and DEF or SUR is a U-shape or inverted U-shape.

*SCALE* indicates the scale effects (the actual GDP (ten thousand dollars) / land area (square kilometer)) referring to Antweiler et al. (2001).

*STR* expresses the structural effects (national capital K / human capital L) referring to Antweiler et al. (2001), which represents the capital held by a country's industry and weighs its industrial structure.

*TECH* represents the technical effects (TECH =ln (patentt + 1)). The number of licensed patents by a country is used to judge its technical development level referring to Dong et al. (2020).

**Control variables:** Referring to Kolcava et al. (2019), the control variables involved in this paper are elaborated as follows. FDI （the natural logarithm of foreign direct investment amount）is used to express the effect of foreign direct investment on pollution transfer amount. OPEN ((total export amount + total import amount) / actual GDP of that year) descript the impact of a country’s trade openness on pollution transfer amount. In addition, POP (the natural logarithm of national population) is selected here to determine the effect of the national consumption scale on pollution transfer amount. Considering the urbanization rate and land area are the important factors, this paper uses URB (urban population/ national population) and AREA (the natural logarithm of national land area) as control variables affecting pollution transfer amount. RE (the supervision quality score of government departments) is necessarily taken as a control variable to represent the influence of environmental regulations on pollution transfer amount, since environmental regulations are government departments' supervision tools of the import and export of pollutants. The data of the above variables were obtained from the World Bank database.

**Table 1.** Construction of data

| Classification | Variable name | Variable symbol | Variable-definition |
|---|---|---|---|
| Dependent variables | Outwards pollution transfer amount | DEF | (EF import - EF export) / (EF export + EF import) |
| | Inwards pollution transfer amount | SUR | (EF export - EF import) / (EF export + EF import) |
| Independent variables | Per capita GDP | Y | Per capita GDP (US $100,000) |
| | Scale effect | SCALE | The actual GDP (ten thousand dollars) / land area (square kilometer) |
| | Structural effect | STR | National capital K / human capital L |
| | Technical effect | TECH | Natural logarithm of (the number of licensed patents +1) |
| Control varia- | Foreign direct invest- | FDI | Natural logarithm of the domestic inflow of FDI |

| | | | |
|---|---|---|---|
| bles | ment | | |
| | Open degree | OPEN | (Total export + total import) / actual GDP |
| | Population | POP | The natural log of the national population |
| | Urbanization rate | URB | The urban population's proportion of all national population |
| | Acreage | AREA | The natural logarithm of national land area |
| | Environmental regulation | RE | The supervision quality score of government departments |

### 4.2. Model construction

Considering that the differences between countries may affect the regression results and the fixed effects can also partially eliminate endogenous problems caused by the omission of difficult-to-observe variables in different countrie, this paper adopts the country fixed effect model. Referring to previous works by Grossman and Krueger (1992), Antweiler et al. (2001) and Kolcava et al. (2019), the model is set as follows:

$$Dependent_{it} = \omega_i + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 SCALE_{it} + \beta_4 STR_{it} + \beta_5 TECH_{it} + \beta_6 Control_{it} + \sum_m \lambda_m \, Country_m + \varepsilon_{it}$$

Dependent represents DEF and SUR, i and t represent the country and the year respectively. Y indicates the per capita GDP. SCALE describes the scale effect. STR measures the structural effect. TECH depicts the technical effect. Control represents the control variables FDI, OPEN, POP, URB, AREA, and RE.

## 5. Empirical results

### 5.1. Descriptive statistics

In Table 2, DEFICIT and SURPLUS represent outward pollution transferring countries and inward pollution transferred countries respectively. The results show that the average per capita GDP of outward pollution transferring countries reaches 1.227 (US $100,000), roughly 3 times higher than that of inward pollution transferred countries, which verifies the PHH (pollution transfer from high-income countries to low-income countries) preliminarily. By comparing their structural and technological effects, the industrial structure of outward pollution transferring countries is better than that of inward pollution transferred countries while so does the technical level, which indicates that there are obvious differences in the industrial models between these two types of countries. In view of the above huge differences and also entirely opposite directions of pollution transfer between these two types of countries, it is essential to conduct empirical research on the relationship between pollution transfer amount and economic development by dividing them into outward pollution transferring countries and inward pollution transferred countries.

**Table 2.** Descriptive statistics

| Variable | Classification | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| DEF | DEFICIT | 0.139 | 0.091 | 0.002 | 0.476 |

| | | | | | |
|---|---|---|---|---|---|
| SUR | SURPLUS | 0.209 | 0.120 | 0.001 | 0.662 |
| Y | DEFICIT | 1.227 | 4.776 | 0.000 | 48.086 |
| | SURPLUS | 0.485 | 1.433 | 0.000 | 9.310 |
| SCALE | DEFICIT | 5.258 | 3.660 | 0.000 | 14.001 |
| | SURPLUS | 4.857 | 14.332 | 0.000 | 93.106 |
| STR | DEFICIT | 1.377 | 2.036 | 0.000 | 11.798 |
| | SURPLUS | 3.832 | 3.134 | 0.732 | 12.594 |
| TECH | DEFICIT | 21.997 | 2.337 | 15.820 | 26.039 |
| | SURPLUS | 2.393 | 2.112 | 0.249 | 10.291 |
| FDI | DEFICIT | 21.111 | 2.978 | 6.908 | 27.322 |
| | SURPLUS | 22.250 | 1.790 | 15.027 | 25.515 |
| OPEN | DEFICIT | 0.594 | 0.511 | 0.054 | 4.153 |
| | SURPLUS | 0.416 | 0.205 | 0.059 | 0.980 |
| POP | DEFICIT | 16.919 | 1.760 | 12.454 | 21.044 |
| | SURPLUS | 16.529 | 1.200 | 14.950 | 19.144 |
| URB | DEFICIT | 0.596 | 0.231 | 0.167 | 1.000 |
| | SURPLUS | 0.820 | 0.088 | 0.520 | 0.951 |
| AREA | DEFICIT | 11.836 | 1.958 | 6.522 | 16.077 |
| | SURPLUS | 13.961 | 1.427 | 12.079 | 16.106 |
| RE | DEFICIT | 0.062 | 0.101 | 0.000 | 1.052 |
| | SURPLUS | 0.336 | 2.433 | 0.000 | 29.477 |

## 5.2. Correlation statistics

Tables 3 and 4 show that the correlation coefficient between variables is generally less than 0.6, and thus there is no serious collinearity. Without controlling for other influencing factors, the independent variables are significantly correlated with the dependent variables.

**Table 3.** Correlation Statistics

| | Y | SCALE | STR | TECH | FDI | OPEN | POP | URB | AREA | *RE* |
|---|---|---|---|---|---|---|---|---|---|---|
| Y | 1 | | | | | | | | | |
| SCALE | 0.155*** | 1 | | | | | | | | |
| STR | -0.048** | 0.480*** | 1 | | | | | | | |
| TECH | 0.068*** | 0.908*** | 0.506*** | 1 | | | | | | |
| FDI | 0.071** | 0.693*** | 0.441*** | 0.815*** | 1 | | | | | |
| OPEN | 0.144*** | 0.063*** | 0.343*** | 0.100*** | 0.331*** | 1 | | | | |
| POP | 0.093*** | 0.568*** | -0.139*** | 0.582*** | 0.432*** | -0.287*** | 1 | | | |
| URB | 0.038 | 0.400*** | 0.557*** | 0.486*** | 0.488*** | 0.439*** | -0.261*** | 1 | | |
| AREA | -0.030 | 0.387*** | -0.236*** | 0.463*** | 0.260*** | -0.505*** | 0.845*** | -0.306*** | 1 | |
| RE | -0.055* | -0.149*** | -0.249*** | -0.154*** | -0.191*** | -0.226*** | 0.140*** | -0.220*** | 0.208*** | 1 |

Standard errors in brackets

* p<0.05, ** p<0.01, *** p<0.001

**Table 4.** Statistics of correlation of inwards pollution transfer countries

| | Y | SCALE | STR | TECH | FDI | OPEN | POP | URB | AREA | RE |
|---|---|---|---|---|---|---|---|---|---|---|
| Y | 1 | | | | | | | | | |
| SCALE | 0.950*** | 1 | | | | | | | | |
| STR | -0.065** | -0.023 | 1 | | | | | | | |
| TECH | -0.162*** | -0.104* | 0.679*** | 1 | | | | | | |
| FDI | 0.083 | 0.138** | 0.063 | 0.319*** | 1 | | | | | |
| OPEN | 0.155*** | 0.220*** | 0.642*** | 0.685*** | 0.230*** | 1 | | | | |
| POP | -0.041 | -0.019 | -0.494*** | -0.371*** | 0.401*** | -0.416*** | 1 | | | |
| URB | 0.161*** | 0.150*** | -0.043 | 0.068 | 0.130** | 0.075 | -0.323*** | 1 | | |
| AREA | -0.146** | -0.118** | -0.551*** | -0.118*** | 0.520*** | -0.387*** | 0.838*** | -0.149*** | 1 | |
| RE | -0.044 | -0.041 | -0.098* | -0.127*** | -0.091 | -0.208*** | 0.220*** | -0.084 | 0.154*** | 1 |

Standard errors in brackets

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

### 5.3. Regression results analysis

The regression results are shown in Table 5. The fixed effect regression results (FE) of outward pollution transferring countries and inward pollution transferred countries are respectively listed in column (1) and column (2). In order to ensure the robustness of the results, the random effect regression results (RE) are also arranged in column (3) and column (4) respectively.

Firstly, the empirical analysis of outward pollution transferring countries is conducted. According to the regression results from column (1) in table 5, the sign of Y2 is significantly positive at the 1% level, meaning that there is a "U" relationship between per capita GDP and outward pollution transfer amount, that is, the outward pollution transfer amount will at first decrease and then increase with the economic development. The sign of SCALE is significantly negative at the 1% level, which indicates that the scale effect will effectively inhibit the outwards pollution transfer and cause more domestic pollution. The symbol of STR is significantly positive at the 1% level, which shows that more stringent environmental regulations promote the upgrading of industrial structure with their economic development. These countries will have to increase imports of pollutant products from abroad to compensate the decrease of their own production, which will engender an increase in the amount of pollution transferred out. The sign of TECH is significantly positive at the 1% level, which illustrates that technological progress can effectively eliminate domestic excess capacity and develop technology-intensive industries with low pollution so as to actually transfer pollution to other countries. Therefore, it can be found that the scale effect reduces the outward pollution transfer amount in the early stage of economic development and exerts a key influence to the left end of the "U" curve. And the structural effect and technical effect increase the outward pollution transfer amount and impose a dominated action to the right end of the "U" curve. The consistency of results from both column (3) and column (1) imply that the U-shape curve relationship is similarly obtained by both fixed-effect regression and the random-effect regression. Hypothesis 1 has thus been verified.

The next analysis is the empirical results of the inward pollution transfer countries. In column (2), the symbol of Y2 is significantly negative at 1%, indicating that there is an inverted "U" relationship between per capita GDP and inward pollution transfer amount. That is, inward pollution transfer amount will first increase and then decrease with their economic development. These countries had to rely on sacrificing environmental quality to produce more polluting products for economic development and employment issues in the initial stage of development. When their economy develops to a certain level, they will begin to turn their focus to improving environmental quality and formulating environmental regulations. The result of this changeover reduced the production and export of pollutant products and declined the EF surplus, thus decreasing the inward pollution transfer amount. In order to better illustrate this relationship, the regression results of three effects are presented. The sign of SCALE is significantly positive at the 1% level, which suggests that scale effects can raise the inward pollution transfer amount and aggravate them to become "pollution havens." The sign of STR is significantly negative at the 1% level while the sign of TECH is significantly negative at the 1% level, which shows that these countries will gradually produce fewer and fewer pollution-intensive and capital-intensive products and reduce the inward pollution transfer amount due to their industrial structure upgrading. Furthermore, technological progress brought by technological effects also promotes the development of technology-intensive industries with less pollution and reduces the inward pollution transfer amount. The uniformity of results from both column (2) and column (4) indicates that the inverted U-shape curve relationship is tenable by both fixed-effect regression and random-effect regression. Hypothesis 2 has thus been proved.

**Table 5.** Table of fixed and random effects regression results

| | DEF | SUR | DEF | SUR |
|---|---|---|---|---|
| | FE | FE | RE | RE |
| | (1) | (2) | (3) | (4) |
| Y | -0.1396*** | 3.5244*** | -0.0772*** | 0.5110*** |
| | [0.0289] | [0.4975] | [0.0235] | [0.1312] |
| Y2 | 0.0259*** | -6.8239*** | 0.0117** | -0.1520** |
| | [0.0069] | [0.7428] | [0.0058] | [0.4978] |
| SCALE | -0.0059*** | 0.0250*** | -0.0071*** | 0.0017** |
| | [0.0014] | [0.0032] | [0.0014] | [0.0028] |
| STR | 0.0124*** | -0.0200*** | 0.0120*** | -0.0115*** |
| | [0.0017] | [0.0053] | [0.0016] | [0.0027] |
| TECH | 0.0120*** | -0.0222*** | 0.0121*** | -0.0011** |
| | [0.0034] | [0.0045] | [0.0031] | [0.0045] |
| FDI | -0.0008 | 0.0019 | -0.0007 | 0.0117*** |
| | [0.0007] | [0.0026] | [0.0007] | [0.0033] |
| OPEN | 0.0336*** | 0.1170** | 0.0336*** | -0.0325 |
| | [0.0060] | [0.0423] | [0.0056] | [0.0325] |
| POP | 0.0184 | -0.0646 | 0.0046 | -0.0816*** |
| | [0.0112] | [0.0650] | [0.0078] | [0.0085] |

| | | | | |
|---|---|---|---|---|
| URB | 0.0343 | 0.7910** | 0.0647* | 0.4010*** |
| | [0.0334] | [0.2640] | [0.0290] | [0.0505] |
| AREA | -0.0860 | -0.1540* | -0.0234** | -0.0000 |
| | [0.1183] | [0.0716] | [0.0072] | [0.0087] |
| RE | -0.0357** | -0.0002 | -0.0398*** | -0.0006 |
| | [0.0122] | [0.0013] | [0.0120] | [0.0016] |
| C | 0.5910 | 2.6830 | 0.0600 | 1.0430*** |
| | [1.3898] | [1.3988] | [0.0785] | [0.0921] |
| N | 1053 | 297 | 1053 | 297 |
| F | 41.52*** | 15.39*** | | |
| Wald chi2 | | | 483.07*** | 792.17*** |
| adj.R-sq | 0.2793 | 0.3338 | 0.4726 | 0.7354 |

Standard errors in brackets

* p<0.05, ** p<0.01, *** p<0.001

## 6. Discussion

The contribution of this paper is that the TEKC has been presented based on EKC, which could be an important guidance in the field of research on pollution transfer and economic development. As a result, an improved EKC model is required to explain the transnational pollution transfer caused by international trade. proposed in this paper essentially reveals the problem of "transnational pollution trade" hidden behind international economic and trade, and expands the research focus of alleviating environmental problems from home to abroad.

The TEKC could theoretically be taken as a tool in common use if possible and necessary. Its research objects can be expanded purposefully, such as the Belt and Road, ASEAN, or the European Union, etc. Moreover, this model can also be used to investigate whether such nonlinear relationships in pollution transfer exist in specific industries between countries.

In this paper, in addition to the "pollution haven" hypothesis having been verified, more findings have been acquired in this research. The "U" curve for outward pollution-transferring countries has been obtained in the study, which is completely opposite to the inverted "U" curve for inward pollution-transferring countries. The reason is that the economic development periods of the latter relative to the former were delayed in time intervals. In the beginning, some outward pollution-transferring countries were in a period of economic booming and some of their polluting industries still gathered domestically, while those inward pollution-transferring countries were far less developed. In the next phase, once the outward pollution transferring countries have crossed the inflection point of the "U" curve, their outward pollution transfer amount will begin to increase gradually. Meanwhile, those inward pollution transferred countries were achieving a leap-forward economic development and were on the left of the inflection point in the inverted "U" curve, whose inward pollution transfer amount was also increasing fast. Thus, the TEKC of the latter relative to the former forms an obvious concave-convex corresponding relationship. For example, in China since the 1990s, many polluting industries have been introduced in order to achieve a leapfrog economic development at the expense of environmental degradation. this period, many western developed countries have crossed the inflection point of the TEKC and realised their domestic industrial transformation, while the increase in outward pollution transfer amounts from these countries has precisely been matched by the increase in inward pollution transfer amounts into China. Dynamically, with the development of the economy, the "pollution haven" countries are unceasingly changing, which can be called the "pollution haven shifting phenomenon." In the middle of the last century, the pollution-intensive industries shifted from the United States to Germany and Japan; by the middle and late 20th century, from Japan to the Asian Tigers; and then to China until the end of the late 20th century. Due to the lack of other annual data, the above analysis of the "pollution refuge shifting phenomenon" in this paper was based on the data spanning 1990–2016, and a more complete study should have been carried out if the data spans were adequate. Similar research will be able to be conducted on the basis of the above in the future.

The TEKC obtained in this paper also showed an inverted "U" type curve similar to the inverted "U" type curve of EKC, that is, the inward pollution transfer amount increases first and then decreases with economic development. In recent years, according to the conclusion inferred by EKC, it is being increasingly accepted that some countries will be able to improve the environment by upgrading their governance ability commensurate with their higher level of economic development. However, it is being debated and has not been positively addressed whether this improvement was done entirely domestically with no pollution transfer outward. If EKC were regarded as the relationship between pollution emissions and domestic economic level (internal), TEKC would have been regarded as the relationship between transnational pollution transfer and different countries' economic levels (external and internal). Internally, with the improvement of its economic development level, stricter environmental regulations drive the upgrading of its industrial structure and the progress of its technology, which reduces the pollution emissions from such internal constraints. Yet it is incomplete to only research domestic situations. The industrial upgrading of a country means that some of its pollution-intensive industries need to be shifted to other countries, which involves transnational pollution transfer. The TEKC suggested in this paper can precisely state that the transnational pollution transfer is the result of the combined action of both internal effects (three effects) and external effects (EF trade). Therefore, the TEKC will examine the relationship between environmental improvement and economic development more comprehensively.

## 7. Research conclusions

In this research, the TEKC is proposed and verified through an empirical study on the relationship between transnational pollution transfer and economic development based on the balanced panel data of 39 outward pollution transferring countries and 11 inward pollution transferring countries from 1990 to 2016. During this process, concerning the scale effect, technology effect, and structure effect, the benchmark regression results were analyzed, including both the fixed effect regression results and the random effect regression results, by the corresponding model, constructed from the new perspective of the difference between EF import and export. The robustness of the model has been validated by endogeneity tests and regression analysis with the replacement and increase of variables. The study highlighted in this paper highlights the non-linear characteristics of pollution transfer with economic development and extends the relevant research to the field of transnational pollution transfer with a new TEKC model instead of the previous EKC one, which provides a theoretical basis and practical guidance for further application.

The results of this study demonstrate that for outward pollution transfer countries, the relationship between outward pollution transfer amount and economic growth is a U-shaped curve. The scale effect inhibits the outward pollution transfer amount while the technology effect and scale effect promote it. Environmental regulations promote outward pollution transfer when it is greater than the threshold value. For inward pollution transferred countries, the relationship between inward pollution transfer amount and economic growth is an inverted U-type curve. The scale effect stimulates the inward pollution transfer while the technology effect and scale effect curb the inward pollution transfer. The environmental regulations will inhibit the inward pollution transfer when it is greater than the threshold value.

For outward pollution-transferring countries, the policy suggestions are given as follows: Firstly, with the improvement of technology and industrial transformation, in the process of transferring polluting industries out, outward pollution transferring countries export green industrial technology to help underdeveloped countries improve their industrial capacity, so as to reduce the pollution emission per unit output value and form a "pollution halo" rather than a "pollution haven". Secondly, it is beneficial for pollution transferring countries to deepen environmental cooperation with pollution transferring countries rather than just transfer pollution one way.

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