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Terms of trade, ecologically unequal exchange and environmental problems in developing economies

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Abstract

Purpose – Utilizing the Marxist theory of unequal exchange to explain the terms of trade between nations, this paper elucidates one possible mechanism that gives rise to ecologically unequal exchange between developed and developing economies.

Design/methodology/approach – We propose a two-sector linear production model and demonstrate that a decrease in the organic composition of capital and an increase in the rate of surplus value in a sector will lead to a relative price decrease and value transfer out of that particular sector, as well as increasing the environmental costs of trade. Furthermore, we measure the levels of unequal exchange (value transfer) and ecologically unequal exchange of 40 economies and empirically validate their relationship.

Findings – The findings suggest that an important cause of the ecologically unequal exchange is the value transfer between economies caused by the international division of labor and real wage disparities. The inequality in international trade is a significant factor contributing to the gap in the ecological environment level between developed and developing economies.

Originality/value – By introducing the theory of unequal exchange or value transfer into the analysis of ecological unequal exchange, we provide a mathematical framework for analyzing ecological unequal exchange and a method for calculating the scale of ecological unequal exchange and value transfer, thereby enhancing the theoretical depth and practical significance of the ecological unequal exchange theory.

Keywords Ecologically unequal exchange, Unequal exchange, Terms of trade

Paper type Translated paper

1. Introduction

In recent years, many developing economies, exemplified by China, have experienced rapid industrialization and economic growth, accompanied by increased resource exploitation and mounting environmental pressures, while developed economies have significantly improved their ecological environments during this period. Neoclassical economists have introduced several theoretical perspectives, including the Environmental Kuznets Curve (EKC) and the "Pollution Haven" hypothesis, to address the widening environmental disparities between the Global North and South, all of which tend to view environmental problems in developing economies as intrinsic to those economies, whether it is the EKC's view on the developmental stage of the developing economies or the pollution haven hypothesis's emphasis on the lack of stringent environmental regulation in developing economies. However, some Marxist economists hold divergent perspectives. They argue that these neoclassical theories overlook

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the crucial "center-periphery" structure under economic globalization in the capitalist world system (Prebisch, 1959; Dos Santos, 1999). When examining the environmental disparities between the Global North and South within the framework of the center-periphery structure, it becomes evident that environmental degradation in developing economies cannot be attributed solely to their characteristics; developed economies also play a significant role in this phenomenon.

The EKC hypothesizes that changes in the ecological environment are primarily attributed to the varying stages of economic development. Economies undergoing industrialization experience environmental degradation due to the rise of manufacturing activities, while economies that have completed the industrialization process tend to have less environmental pressure due to improvements in manufacturing environmental efficiency and a gradual shift towards a service-based economy (Beckerman, 1992; De Bruyn *et al*., 1998; Dinda, 2004; Lin and Jiang, 2009; Xu and Song, 2010; Sheng and Lyu, 2012). This model describes the trajectory of developed economies; however, it remains uncertain whether developing nations can replicate this process (Røpke, 1994; Clark and Foster, 2009; Bonds and Downey, 2012). The increase in environmental efficiency in the production processes within developed economies is not solely attributable to technological progress, as a significant portion of this improvement is due to the transfer and outsourcing of highly polluting sectors to developing economies. Besides, the servitization of the economy gains resulting from "de-industrialization" are partially due to the offshoring of low-end manufacturing. These processes are not easily replicable in developing economies (Andersson and Lindroth, 2001; Lynch, 2016).

In comparison, the pollution haven hypothesis seems to capture the core issue by emphasizing the relocation of polluting sectors, which posits that the lack of stringent environmental regulation in developing economies makes these regions more attractive to high-pollution sectors. Such theories highlight that the environmental disparities between the Global North and South result from environmental burden redistribution (Brunnermeier and Levinson, 2004; Kheder and Zugravu, 2008; Wagner and Timmins, 2009; Leiter *et al*., 2011; Yang and Tian, 2017). However, these theories do not adequately address the underlying question: What causes these underdeveloped economies to be more inclined to provide a lenient regulatory environment for polluting enterprises? If there is a systematic disparity in regulatory stringency between the Global North and the South, it may suggest endogeneity of environmental regulation (Goldman, 2006; Brand *et al*., 2008).

Eco-Marxist scholars, such as Hornborg (1998, 2009, 2014), Andersson and Lindroth (2001), Rice (2007), and Roberts and Parks (2009), have moved beyond this line of thinking that attributes ecological disparities between the Global North and South solely to the inherent characteristics of individual economies. Instead, they directly point to the structural of the world market as the primary explanatory factor. They argue that although international trade adheres to the principle of equivalent exchange, the environmental costs associated with a given trade volume measured in monetary terms differ significantly between developed and developing economies. This suggests that developed economies exchange goods produced at a lower environmental cost for goods with a higher environmental cost from developing economies. This phenomenon mirrors the Marxian concept of "unequal exchange," where developed economies exchanging less labor for more labor in developing economies in international trade. Similarly, the trade dynamics in which developed economies benefit from its goods with lower environmental costs at the expense of higher environmental costs in developing economies is called "ecologically unequal exchange."

The phenomenon of ecologically unequal exchange appears closely related to the technological disparity between the Global North and the Global South. If developed economies employ cleaner technologies, the environmental costs embedded in their products will naturally be lower. Consequently, these economies would trade lower environmental costs for higher environmental costs of developing economies. However, some ecological Marxist scholars argue that this seemingly reasonable explanation is insufficient. Consider that when developed and developing countries produce homogeneous products, there is indeed a difference in environmental efficiency for the same product. Developed economies can manufacture a product with lesser environmental costs, suggesting that ecologically unequal exchange merely reflects technological differences between the Global North and the Global South. However, in most cases, international trade between these regions often involves heterogeneous products, and the technologies used to produce different products are not directly comparable, necessitating a common unit of measurement: money. Whether a product is resource- or environmentally intensive can essentially only be measured by the amount of resources and environmental cost per monetary unit of it. If the price of a kind of product is systematically suppressed, the ecological cost inherent in a given amount of monetary output inevitably increases. Thus, pricing plays a crucial role in determining whether a production technology is "clean". Numerous studies indicate that products from developing economies are priced lower, resulting in a greater ecological burden for these economies in trade exchanges (Andersson and Lindroth, 2001; Røpke, 2001; Shandra *et al*., 2009; Frey *et al*., 2019). In addition to the acknowledged technological gap, ecological Marxist scholars also identified a crucial correlation between the price issue in the trade and the ecological disparities between the Global North and South.

The ecologically unequal exchange reveals the relationship between sectoral price factors and the resource or environmental intensity of the sectors. This relationship also elucidates a critical source of the endogeneity of regulatory stringency posited by the pollution haven hypothesis. Despite similar technical levels between the Global South and North, industries in developing economies may exhibit relatively inferior environmental performance and higher resource intensity due to their generally lower product prices than those from developed economies. Consequently, it is not a matter of developing economies tolerating more polluting sectors *per se*. As long as the terms of trade between the North and South remain unchanged, the pollution levels of firms in developing economies, when measured in monetary terms, will always surpass those in developed economies regardless of how stringent their regulations might be. This implies that developing economies are simply compelled to "tolerate" their local industries. However, merely identifying the relationship between ecologically unequal exchange and price factors is insufficient. The definition of ecologically unequal exchange implies that the environmental costs in equivalent monetary amounts differ in different countries. The crux of the issue lies in understanding why prices fail to adequately reflect environmental costs or why the product prices in developing economies are systematically lower than those in developed economies.

There are two main perspectives in the literature addressing this issue. One follows the Prebisch-Singer hypothesis, utilizing the technological nature of the international division of labor to explain the deterioration of terms of trade for developing economies (Pérez-Rincón, 2006). The primary challenge with this explanation is that the Prebisch-Singer hypothesis assumes that core economies supply industrial goods and peripheral economies provide raw materials and primary products. However, as previously noted, we are currently dealing with the rapid industrialization of developing economies and the accompanying environmental problems. Therefore, these assumptions no longer fully apply to the present global system.

An alternative perspective involves leveraging the monopolistic power of developed economies in the global market, positing that distortions in terms of trade stem from such market power (Andersson and Lindroth, 2001; Røpke, 2001; Taylor *et al*., 2016). While it is true that developed economies possess monopolistic power in the global market, this view only applies to very limited situations. Contemporary political economy theories predominantly assert that the global market remains highly competitive. Lenin (2015) pointed out that the development of capitalism into its monopoly stage does not eradicate competition but creates new competition at a higher level. This view has been consistently upheld by subsequent scholars studying monopoly capitalism. Even the Monopoly Capital School, which focuses heavily on issues of monopoly, posits that monopoly is a domestic characteristic of developed economies post-World War II, which cannot be directly applied to the global market, and argues that monopolists from various economies face even fiercer competition in the international arena (Baran and Sweezy, 1977; Sweezy, 1997; Foster *et al.*, 2011). Fundamentally, as Gao (1996) noted, exploitation and competition are capitalism's two fundamental relationships. Competition among different capitals, each pursuing capital proliferation, is inevitable. Empirical research on contemporary capitalism also supports the reality of a highly competitive global market (Brenner, 2003, 2006; Sheppard, 2012; Seretis and Tsaliki, 2016; Tsaliki *et al*., 2017).

The approaches above fail to fully explain the disparity in commodity prices between the Global North and South on the global market and thus fail to provide a complete and solid theoretical explanation for ecologically unequal exchange. The primary contribution of this paper lies in proposing a novel framework that differs from the previous two, thereby offering a sound explanation for the relationship between ecologically unequal exchange and pricing.

This paper integrates the theories of unequal exchange and value transfer into the analysis of ecologically unequal exchange. This approach has two significant advantages over the prior approaches: First, it is grounded on weaker and more realistic assumptions of the international division of labor, as it attributes the commodity price differences between Global North and South to disparities in the organic composition of capital and surplus value rates of the north and the south, avoiding the specific industry assumptions inherent in the Prebisch-Singer hypothesis. Second, it is based on the theory of profit equalization; thereby, the theoretical foundation is based on competitive global markets rather than monopolistic ones.

First, this paper provides a mathematical framework for analyzing ecologically unequal exchange. It is the first to rigorously describe ecological unequal exchange under Okishio-Morishima's linear production framework, using deviations between production prices and values to characterize value transfer. Based on it, this paper explains the conditions under which value transfer and ecologically unequal exchange occur and elucidates their theoretical interconnection.

Furthermore, this paper presents an enhanced measurement methodology for assessing value transfer and ecologically unequal exchange. On this basis, it firstly uses introduces regression analysis to empirically validate the real-world association between value transfer and ecologically unequal exchange between the Global North and South.

The structure of the paper is as follows: the second section elaborates on the theoretical framework and model construction; the third section explores the methods for assessing value transfer and ecologically unequal exchange; the fourth section details the regression model specifications and data sources; the fifth section analyzes the regression results; and the final section concludes the study.

2. Theoretical framework

2.1 The theoretical connection between value transfer and ecologically unequal exchange

As stated in the first section, a significant cause of ecologically unequal exchange is the price disparity between the Global South and North. Traditional unequal exchange theories explain this systematic price disparity through the labor theory of value. According to the fundamental principles of the labor theory of value, if goods are exchanged at their value, i.e. the socially necessary labor time, enterprises with labor productivity equal to the sector average should have equivalent per capita output or value-added. However, in a perfect competitive market with unrestricted capital mobility between sectors, the unimpeded flow of capital will result in profit equalization across sectors. Consequently, sectors with a higher organic composition of capital or a lower rate of surplus value will have prices that exceed their values, while the opposite will be true for other sectors. This deviation of price from value generates a value transfer. The value transfer implies that even if the relative labor productivity levels of enterprises in each sector are similar, the per capita value added of enterprises in the value-receiving sector and those in the value-transferring sector are completely different. Workers in the latter sector have to exert more labor to achieve the same value added as those in the former sector (Marx, 2004a, b).

The theory of unequal exchange leverages the concept of value transfer. Bauer (2000) and Grossmann (1992) posited that developed capitalist economies hold advantageous positions in the international division of labor due to their capital abundance, engaging in sectors with a higher organic composition of capital and thereby benefiting from this value transfer. Emmanuel (1988) argued that real wages in developed economies are higher, implying a lower rate of surplus value. Following these lines of thought, subsequent scholars have conducted extensive theoretical and empirical research and confirmed the existence of unequal exchange (Gibson, 1980; Foot and Webber, 1983; Nakajima and Izumi, 1995; Tsaliki *et al*., 2017). Consequently, when labor productivity levels are similar, enterprises in developing economies generate lower per capita added value compared to those in developed economies and need to invest more labor to achieve the same monetary returns as those in developed economies. Therefore, developed economies utilize less labor in exchange for more labor from developing economies (Feng, 2016a).

According to the logic of ecologically unequal exchange mentioned above, if there are international differences in prices, then it is evident that developing economies incur higher costs in these exchanges. Given similar efficiency in the production environment of products, developing economies need to use a larger quantity of their products — because of lower per capita value added — to exchange for fewer products from developed economies. Consequently, this exchange results in exchange for a larger environmental cost in developing countries for a smaller environmental cost in developed countries. Therefore, regarding equivalent monetary outputs, developing economies exhibit poorer environmental efficiency.

In summary, differences in the organic composition of capital and wage lead to international value transfer. When such value transfers occur, ecologically unequal exchanges accompany them. This paper aims to test this theory by constructing a model that addresses two key questions: First, does an increase in the organic composition of capital and real wages lead to value transfer? Second, if value transfer occurs under these conditions, does ecologically unequal exchange also occur? If the answer to both questions is yes, then we can identify a theoretical link between value transfers and ecologically unequal exchange. While the answers to these questions may seem straightforward, they are more complex. At least two points of ambiguity are present.

First, though the rise in the organic composition of capital does lead to an increase in production prices, it also signifies a relative growth of materialized labor compared to living labor. Therefore, although production prices go up, the value embodied in the commodities also increases. If the newly added value exceeds the increase in production price, an increase in the organic composition of capital may also lead to a transfer out of value. Similarly, in the context of ecologically unequal exchange, the rise in the organic composition of capital implies that the ecological costs embedded in the means of production increase relative to direct ecological costs, thereby increasing the overall ecological cost of the product. If the change in terms of trade resulting from the rise in production prices fails to offset the increased ecological costs, it may indicate that the increased organic composition of capital does not enable the sector to exchange lower ecological costs for higher ones.

Second, an increase in real wages not only leads to a decline in the rate of surplus value, resulting in a rise in the production price relative to value but also exerts an additional impact by reducing the organic composition of capital, which may lower production prices.

Therefore, it is imperative to construct a mathematical model to analyze which of these two opposing effects of the organic composition of capital and the rate of surplus value is dominant under various conditions, thereby determining the specific conditions under which the organic composition of capital and real wages can lead to value transfer and ecologically unequal exchange.

2.2 Basic settings of the model

For the sake of clarity and simplicity of the model, we construct an Okishio–Morishima model characterizing 2 sectors $\times$ 2 products $\times$ 2 economies. Assume there are 2 sectors and 2 economies, with each economy engaging in one sector, and each sector produces one type of product. To discuss value transfer and ecologically unequal exchange, we need to establish three sets of equations to represent the value system, environmental input and production price system, respectively. The value system is defined by

$$a_{11}\lambda_1 + a_{12}\lambda_2 + l_1 = \lambda_1 \tag{1}$$

$$a_{21}\lambda_1 + a_{22}\lambda_2 + l_2 = \lambda_2 \tag{2}$$

or in matrix form:

$$A\lambda + l = \lambda$$

where a_{ij} represents the intermediate input coefficient, i.e. the means of production, denoting the quantity of product j required to produce one unit of product i; l_i the direct labor input coefficient, indicating the amount of living labor required to produce one unit of product i and λ_i the unit value of product i. The intermediate input and the direct labor input coefficients are exogenously determined by the respective sector's technology (Morishima, 1973).

Based on equations (1) and (2), the unit values of the two commodities are derived as:

$$\lambda_1 = [l_1(1 - a_{22}) + a_{12}l_2]|I - A|^{-1}$$

$$\lambda_2 = [l_2(1 - a_{11}) + a_{21}l_1]|I - A|^{-1}$$

where $\boldsymbol{I}$ is the second-order unit matrix.

The environmental input system can be represented similarly to the value system in an input-output framework as follows:

$$a_{11}e_1 + a_{12}e_2 + f_1 = e_1 \tag{3}$$

$$a_{21}e_1 + a_{22}e_2 + f_2 = e_2 \tag{4}$$

or represented in matrix form:

$$Ae + f = e$$

where f_i denotes the direct environmental input coefficient, representing the amount of direct environmental input required to produce one unit of product i. To maintain generality, we have not specified what type of environmental input f_i is. The total environmental input required to produce one unit of product i is denoted by e_i. The intermediate input and direct environmental input coefficients are exogenously given technological variables.

Similarly, we can determine the total environmental input per unit of product for the two sectors by solving equations (3) and (4):

$$e_1 = [f_1(1 - a_{22}) + a_{12}f_2]|I - A|^{-1}$$

$$e_2 = [f_2(1 - a_{11}) + a_{21}f_1]|I - A|^{-1}$$

Regarding the production price system, we assume that the quantity of consumption goods required per unit of labor time is exogenously given according to the theory of the value of labor (Marx, 2004a), thus:

$$[(a|\ |11+b_{11}l_1)p_1 + (a_{12} + b_{12}l_1)p_2](1 + r) = p_1 \quad (5)$$

$$[(a|\ |21+b_{21}l_2)p_1 + (a_{22} + b_{22}l_2)p_2](1 + r) = p_2 \quad (6)$$

where b_{ij} represents the quantity of consumption good j required per unit of labor for the production of product i; $\sum_j b_{ij}p_j$ the wage obtained by the worker per unit of labor under the production price conditions (b_{ij} is exogenously given); p_i the production price of one unit of product in sector i; and r the average profit rate. Since we are only concerned with the relative prices of the two sectors, i.e. $p = p_1/p_2$, we can eliminate one unknown variety with the relative price, resulting in a perfectly-identified model. For simplicity, we define the total quantity of product j required for one unit of product i as $c_{ij} = a_{ij} + b_{ij}l_i$. Based on the above points, equations (5) and (6) are reorganized into:

$$(c_{11}p + c_{12})(1 + r) = p \quad (7)$$

$$(c_{21}p + c_{22})(1 + r) = 1 \quad (8)$$

According to equations (7) and (8), the economically meaningful relative price can be expressed as [1]:

$$p = \left[(c_{11} - c_{22}) + \sqrt{4c_{12}c_{21} + (c_{11} - c_{22})^2}\right] \Big/ 2c_{21}$$

2.3 Conditions for value transfer and ecologically unequal exchange

In this section, we explore how the change in the organic composition of capital and the rate of surplus value impact value transfer and unequal ecological exchange. Under the current model framework, the representations of the organic composition of capital and surplus value rate are fairly intricate, and their relationships with value, environmental input and production price expressions are rather indirect. Therefore, we need to seek new ways to express changes in the organic composition of capital and the surplus value rate.

In theory, change in the organic composition of capital essentially results from the variation in materialized labor, i.e. the means of production relative to living labor. In our model, the means of production are represented by intermediate inputs. Hence, ceteris paribus, change in the intermediate input coefficient, a_{ij}, indicates the change in either materialized labor or constant capital. An increase in a_{ij} implies an increase in materialized labor, whether relative to the value of labor power or the total living labor. Therefore, to study the organic composition of capital, we focus on the change in a_{ij}.

Regarding the rate of surplus value, given a specific level of labor productivity, both the amount of direct labor input and the value of labor power will impact it. Since the theory of unequal exchange primarily attributes the price level disparities between developed and developing economies to wage disparities, we mainly consider the impact of labor power value on the rate of surplus value. Obviously, under the ceteris paribus condition, the higher the number of consumption goods included in the value of labor power, i.e. the real wages, the higher the value of labor power and the lower the rate of surplus value. Therefore, for the rate of surplus value, we primarily consider the change in b_{ij}.

(1) Value transfer

We define $v = p - \lambda_1/\lambda_2$ as the variable representing value transfer. Obviously, the larger v, the greater the relative production price of commodity 1 compared to its relative value, putting its producer in a more advantageous position in the value transfer process.

First, to examine the impact of the change in the consumption goods of workers, we have

$$\partial v/\partial b_{11} = l_1\left(1 + \frac{c_{11} - c_{22}}{\sqrt{4c_{12}c_{21} + (c_{11} - c_{22})^2}}\right)\Bigg/ 2c_{21}$$

and

$$\partial v\Big/\partial b_{12} = l_1\Big/\sqrt{4c_{12}c_{21} + (c_{11} - c_{22})^2}$$

Obviously, $\partial v/\partial b_{12} > 0$. Moreover, given that $c_{11} - c_{22} \vee \sqrt{4c_{12}c_{21} + (c_{11} - c_{22})^2}$, then $-1 < (c_{11} - c_{22})/\sqrt{4c_{12}c_{21} + (c_{11} - c_{22})^2} < 1$ and $\partial v/\partial b_{11} > 0$. Therefore, we have the following inferences.

Inference (1). Given a sector, all else being equal, an increase in the actual wages of its workers will lead to a rise in the production price relative to the value in that sector.

Next, we consider the impact of means of production a_{ij}. The first to consider is the change in a_{11}. Due to the highly complex structure of $\partial v/\partial a_{11}$, to avoid unnecessary complexity, we examine a monotonically increasing function v' of v: $v' = p/(\lambda_1/\lambda_2)$, under the conditions $p > 0$ and $\lambda_i > 0$. Since the derivate of function v' and v have the same sign, we have

$$\frac{\partial v'}{\partial a_{11}} = \frac{\left[(c_{11} - c_{22}) + \sqrt{4c_{12}c_{21} + (c_{11} - c_{22})^2}\right]\left[a_{21}l_1 + l_2(1 - a_{11}) - l_2\sqrt{4c_{12}c_{21} + (c_{11} - c_{22})^2}\right]}{2c_{21}[a_{12}l_2 + l_1(1 - a_{22})]\sqrt{4c_{12}c_{21} + (c_{11} - c_{22})^2}}$$

Obviously, except for $a_{21}l_1 + l_2(1 - a_{11}) - l_2\sqrt{4c_{12}c_{21} + (c_{11} - c_{22})^2}$, all terms in the above equation are greater than 0, so the sign of $\partial v'/\partial a_{11}$ is decided by the sign of this expression.

In addition, the impact of a_{12} should be considered, then we have

$$\frac{\partial v}{\partial a_{12}} = \frac{a_{21}l_1 + l_2(1 - a_{11}) - l_2\sqrt{4c_{12}c_{21} + (c_{11} - c_{22})^2}}{[a_{21}l_1 + l_2(1 - a_{11})]\sqrt{4c_{12}c_{21} + (c_{11} - c_{22})^2}}$$

We have found that the sign of $\partial v/\partial a_{12}$ also depends on the expression $a_{21}l_1 + l_2(1 - a_{11}) - l_2\sqrt{4c_{12}c_{21} + (c_{11} - c_{22})^2}$, which indicates that a rise in the proportion of means of production in sector 1 will lead to a rise in the production price relative to the value only if this expression is greater than zero. Given that the inequality is not intuitively clear, we provide a sufficient condition for it to hold, thereby elucidating its potential economic significance.

Proposition (1). If $c_{21}/c_{22} < c_{11}/c_{12}$, and $l_1/l_2 > (1 - a_{22} - c_{11} - c_{22})/a_{21}$, then $a_{21}l_1 + l_2(1 - a_{11}) - l_2\sqrt{4c_{12}c_{21} + (c_{11} - c_{22})^2} > 0$.

The implication of proposition (1) is that given a higher proportion of the output of the Sector 1 used by Sector 1 relative to Sector 2, the ratio of the coefficients on labor inputs in Sector 1 to those in Sector 2 should not fall below a given value if the increase in the means of production is to raise the price of production relative to its value. The Sector 1 uses a higher proportion of its own products that is almost certainly true if one considers that the two sectors are produced by two economies respectively. In most economies, the proportion of intermediate inputs and consumption goods produced locally used in the production process is higher than that used by other economies. The fact that the ratio of the labor input coefficients is greater than one value reflects the balance between the two effects we mentioned at the beginning of this section. If the relative share of the direct labor input coefficient in this sector is extremely low, a rise in the volume of materialized labor will rapidly increase the ratio of the volume of value in this sector to that in another, thus counteracting the impact of the rise in the price of production that it brings about.

It is also worth noting that the condition, $l_1/l_2 > (1 - a_{22} - c_{11} - c_{22})/a_{21}$, is not very demanding; instead, it is quite loose. The reason is that $a_{22} + c_{11} + c_{22}$ is likely to be close to or even greater than 1, and thus, $(1 - a_{22} - c_{11} - c_{22})/a_{21}$ may be very small or even negative. Thereby, there is very little, if any, or even no restriction on the ratio of the coefficients on direct labor input into the two sectors, l_1/l_2. Therefore, we can get the following inference.

Inference (2). If the direct labor input coefficient of a sector exceeds a certain value, the production price will rise relative to the value in that sector when the proportion of constant capital in that sector increases.

According to inferences (1) and (2), we have verified the first question raised at the beginning of this section. An increase in real wages at any time leads to a rise in the production price relative to the value. Also, an increase in constant capital relative to living labor causes an increase in the production price relative to the value when the direct labor input coefficient of the sector is higher than a certain value. This rise in the production price relative to the value will result in the value transfer between sectors. Under the perfect division of labor, this intersectoral transfer of value is also a transfer of value between economies.

(2) Ecologically unequal exchange

Next, we verify the second question raised at the beginning of this section: whether ecologically unequal exchange occurs simultaneously with value transfer. We examine the effect of changes in the consumption coefficients, b_{11} and b_{12}, and the intermediate input coefficients, a_{11} and a_{12}, on $u = pe_2/e_1$. Clearly, pe_2/e_1 represents the exchange ratio of environmental costs in the equivalent exchange process between Sectors 1 and 2. Similarly, changes in the consumption coefficients and intermediate input coefficients represent changes in real wages and the consumption of means of production

Firstly, for the change in consumption goods, we have

$$\frac{\partial u}{\partial b_{11}} = \frac{[a_{21}f_1 + f_2(1 - a_{11})]l_1\left[1 + \frac{c_{11}-c_{22}}{\sqrt{4c_{12}c_{21}+(c_{11}-c_{22})^2}}\right]}{2c_{21}[a_{12}f_2 + f_1(1 - a_{22})]} > 0$$

and

$$\frac{\partial u}{\partial b_{12}} = \frac{[a_{21}f_1 + f_2(1 - a_{11})]l_1}{[a_{12}f_2 + f_1(1 - a_{22})]\sqrt{4c_{12}c_{21} + (c_{11} - c_{22})^2}} > 0$$

Therefore, we have the following inference:

Inference (3). A rise in real wages in a given sector leads to less environmental costs in this sector in exchange for more environmental costs in other sectors and further a decline in the degree of ecologically unequal exchange in this sector.

Next, considering the impact of the constant capital (a_{ij}), we have

$$\frac{\partial u}{\partial a_{11}} = \frac{\left[(c_{11}-c_{22})+\sqrt{4c_{12}c_{21}+(c_{11}-c_{22})^2}\right]\left[a_{21}f_1+f_2(1-a_{11})-f_2\sqrt{4c_{12}c_{21}+(c_{11}-c_{22})^2}\right]}{2c_{21}[a_{12}f_2+f_1(1-a_{22})]\sqrt{4c_{12}c_{21}+(c_{11}-c_{22})^2}}$$

Similar to the structure of value transfer, the sign of $\partial u/\partial a_{11}$ depends on the sign of $a_{21}f_1+f_2(1-a_{11})-f_2\sqrt{4c_{12}c_{21}+(c_{11}-c_{22})^2}$. Given the highly complex structure of $\partial u/\partial a_{12}$, to avoid unnecessary complexity, we examine a monotonically increasing function $u' of\ u : u' = p - e_1/e_2$, under the conditions $p > 0$ and $\lambda_i > 0$. Therefore, we have

$$\frac{\partial u'}{\partial a_{12}} = \frac{a_{21}f_1+f_2(1-a_{11})-f_2\sqrt{4c_{12}c_{21}+(c_{11}-c_{22})^2}}{[a_{12}f_2+f_1(1-a_{22})]\sqrt{4c_{12}c_{21}+(c_{11}-c_{22})^2}}$$

Clearly, the sign of $\partial u'/\partial a_{12}$ depends on $a_{21}f_1+f_2(1-a_{11})-f_2\sqrt{4c_{12}c_{21}+(c_{11}-c_{22})^2}$. Similar to the transfer of value, we can provide an economically meaningful sufficient condition for this expression to be greater than zero.

Proposition (2). If $c_{21}/c_{22} < c_{11}/c_{12}$, and $f_1/f_2 > (1-a_{22}-c_{11}-c_{22})/a_{21}$, then $a_{21}f_1 + f_2\ (1-a_{11}) - l_2\sqrt{4c_{12}c_{21}+(c_{11}-c_{22})^2} > 0$.

Similar to the proposition (1), proposition (2) suggests that a rise in a_{ij} exerts two effects: one is a rise in the exchange ratio of environmental costs by increasing the relative price of output in the sector so that one unit of product in the sector can be exchanged for more products in the other sector; the other is a rise in the total of environmental cost inputs required for one unit of output in the sector in the face of an increase in a_{ij}. As long as the sector's direct environmental cost inputs are not extremely low, the former effect will outweigh the latter, making the ecological cost of the sector in the exchange relatively lower than that of the other sector. From this, we can draw the following inference.

Inference (4). If the coefficient on direct environmental input into a sector is higher than a certain value, the sector can exchange less environmental costs for more environmental costs in other sectors when the proportion of constant capital in this sector rise, which leads to a decrease in the degree of ecologically unequal exchange in this sector.

With inferences (3) and (4), we obtained an answer to the second question originally posed in this section: value transfers and ecologically unequal exchanges occur simultaneously when real wages rise. For a rise in the proportion of the means of production, value transfers and ecologically unequal exchanges occur simultaneously when the value system and environmental inputs system fulfill certain conditions. The conditions to be fulfilled by the two systems include an identical condition, i.e. $c_{21}/c_{22} < c_{11}/c_{12}$. There are also structurally similar but different conditions, namely, $l_1/l_2 > (1-a_{22}-c_{11}-c_{22})/a_{21}$ and $f_1/f_2 > (1-a_{22}-c_{11}-c_{22})/a_{21}$, which are relatively relaxed, and because of the structural similarity, once one condition is satisfied, the other is easily satisfied.

The relationship between ecologically unequal exchange and value transfer is related to the model's structure, where the value system and the environmental input system are isomorphic. The way they are expressed is similar to that of production prices. This similarity is not a deliberate result of the model's design; both systems are general expressions of their input–output relationships. This approximation indicates their theoretical relevance well: both the value and environmental input systems are input–output systems based on certain technical relations, whereas the production price system is logically different. The change in the production price system affects the value and environmental input systems similarly. This model indicates that ecologically unequal exchange and value transfer are, in fact, two sides of the same coin, an elaboration of a same trade process in terms of the terms of trade and ecological impacts; that is, value transfers and ecologically unequal exchanges are isomorphic, occurring simultaneously under similar conditions, and thus we cannot simply interpret their relationship as value transfers being the “cause” of ecologically unequal exchanges. As a description and measure of price differentials, the value transfer is inherently a description of the conditions under which ecologically unequal exchange occurs.

Although the above theoretical propositions and inferences largely explain the relationship between value transfers and ecologically unequal exchange, it is clear that the relation between the two remains contingent in terms of changes in the means of production, as the model gives. Moreover, in reality, there is not only one factor that affects ecologically unequal exchange, and whether the effect of value transfer exists and whether this effect is significant still needs to be verified by empirical evidence. Therefore, we will use empirical analysis to examine whether there is a strong relationship between value transfers and ecologically unequal exchanges in reality in the following section.

3. Calculation of value transfer and ecologically unequal exchange

To examine whether value transfer and ecologically unequal exchange are really related, we first need to measure the amount of value transfer and the degree of ecologically unequal exchange in economies in the empirical analysis method, of which the calculation methods based on the input–output system will be discussed separately in this section.

3.1 Calculation of value transfer

The essence of value transfer is the difference between the value invested or condensed in the production process and the value realized in the exchange process. The latter is the monetary amount obtained in the real exchange process, so the core of calculating the value transfer lies in calculating the amount of labor to be invested in the production process and its monetary representation.

Theoretical methods for calculating the amount of input labor in the production process are well established. According to Marelli (1983) and Ochoa (1989), the amount of value in a commodity economy can be expressed as:

$$(A + D)\lambda + l = \lambda \tag{9}$$

The equation (9) is similar to our model in the second section. The only difference is that it considers the impact of depreciation of fixed capital based on real factors. D is the matrix of depreciation of fixed capital, where d_{ij} denotes the amount of depreciation of fixed capital in sector j required to produce one unit of product of sector i, and we have $\lambda = (I - A - D)^{-1} l$, where I is the identity matrix, and the unit of λ is time. Since the total value and the total market price are equal in monetary terms, the amount of money corresponding to the value per unit of time is defined as $\theta = \sum_i m_i / \sum_i q_i \lambda_i$, where m_i is the total sales revenue of the products from sector I, and q_i the output of products sector i. According to θ, we find the value expressed in money as $\lambda_i = \lambda_i \theta$.

Both A and D in the above method require physical quantities; however, the real input–output system can only provide data for $a_{ij} m_j$ and $d_{ij} m_j$, so we need to re-process these two kinds of data into $a_{ij} = a_{ij} m_j / m_i$ and $d_{ij} = d_{ij} m_j / m_i$, and make corresponding adjustments to l: $l_i = l_i q_i / m_i$. From these adjusted matrices and vectors, the amount of value contained in each unit of money is defined as $\lambda_i = \lambda_i q_i / m_i$, from which we derive the total value of a sector, denoted as $\lambda_i q_i$. When extending the above method to an international input–output system, we encounter a rather complex issue: how to interpret the relationship between the same sectors of different economies in the input–output system.

In an economy's input–output system, the *n* sectors in the input–output table represent *n* kinds of industries. When this system is extended to a multi-regional input-output (MRIO) system, we list *n* sectors of each economy in the input–output table, forming *sn* sectors regarding *s* economies. The question is whether we think that the *sn* sectors are all different sectors, i.e. that they are not substitutable for each other or whether we think they are similar and substitutable. This question is crucial because the value is determined by socially necessary labor time, in an international context, if the *sn* sectors are completely different, each economy's sector-specific value is determined by its own technology and labor input; if specific sectors of each economy are substitutable with those of other economies, then the sectors of different economies are similar to sectors within a local region, and their labor inputs are considered individual labor times that need to be aggregated to determine value as socially necessary labor time. Therefore, in the input–output table, there are only *n* production sectors, and the input–output processes of each sector need to be aggregated to obtain an international average technology before the value of the sector is calculated.

The substitutability of the same sector in different economies cannot be delineated in the international input–output tables, as these tables generally use relatively broad industry classifications, often comprising only a few dozen sectors. Some sectors, such as agriculture and construction, produce similar products in different regions, thus exhibiting a certain degree of substitutability. However, other sectors, like high-tech manufacturing, produce vastly different products in different regions, particularly between the Global North and South. In developing economies, high-tech manufacturing might involve computer assembly, whereas, in developed economies, it might involve chip production. Therefore, there is no substitutability between the two.

However, when measuring the transfer of value, we can conduct assessments under two different assumptions to obtain the upper and lower limits of value transfer. Under the assumption of complete non-substitutability of sectors within each economy, the labor productivity of developing economies is low relative to the productivity of developed economies in terms of the real substitutable sectors, resulting in individual labor times in developing economies exceeding the socially necessary labor time. In this scenario, these individual labor times are treated as socially necessary labor time, thereby overestimating the socially necessary labor time and the corresponding value in developing economies. Under the assumption of complete substitutability of sectors, some non-substitutable sectors are considered substitutable. Given that developing economies often have higher labor intensity, individual labor times are above the socially necessary labor time in the same sector, leading to an underestimation of the value in developing economies. Therefore, under the former assumption, we can estimate the upper limit of value transfer (broad measure), while under the latter assumption, we can estimate the lower limit of value transfer (narrow measure).

(1) Value transfer under the assumption of complete non-substitutability (broad measure)

Under the assumption of complete non-substitutability, calculating the value of each sector of all economies is essentially a simple extension of the Marelli-Ochoa method. Assuming there are *s* economies with *n* sectors, the following equation can be used to calculate the corresponding value:

$$\left[\begin{pmatrix} A^{11} & \dots & A^{1s} \\ \vdots & \ddots & \vdots \\ A^{s1} & \dots & A^{ss} \end{pmatrix} + \begin{pmatrix} D^{11} & \dots & D^{1s} \\ \vdots & \ddots & \vdots \\ D^{s1} & \dots & D^{ss} \end{pmatrix}\right] \begin{pmatrix} \lambda^{1} \\ \vdots \\ \lambda^{s} \end{pmatrix} + \begin{pmatrix} l^{1} \\ \vdots \\ l^{s} \end{pmatrix} = \begin{pmatrix} \lambda^{1} \\ \vdots \\ \lambda^{s} \end{pmatrix} \tag{10}$$

Let A^{xy} and D^{xy} be $n \times n$ matrices, representing the coefficient matrices of intermediate input and depreciation of fixed capital for the products from sector *x* to the products from sector *y*, respectively. Let l^x and λ^x be n-dimensional vectors, representing the vector of direct labor input coefficients and values of sector x, respectively. If we use τ to denote the technical relations under complete non-substitutability in the global market, equation (10) can be further simplified to a more compact form: $(A^\tau + D^\tau)\lambda^\tau + l^\tau = \lambda^\tau$. Clearly, this equation can be transformed into the following form applicable to a value-based input–output table:

$$(A^\tau + D^\tau)\lambda^\tau + l^\tau = \lambda^\tau \tag{11}$$

where $a_{ij}^{xy} = a_{ij}^{xy} m_j^y / m_i^x, d_{ij}^{xy} = d_{ij}^{xy} m_j^y / m_i^x$, and $l_i^x = l_i^x q_i^x / m_i^x$. In addition, conventional input–output tables typically only include the total depreciation of fixed capital of each sector, denoted as $d_i^x = \sum_y \sum_j d_{ij}^{xy} m_j^y$. Therefore, to obtain $d_{ij}^{xy} m_j^y$, i.e. the depreciation of fixed capital goods from sector j of economy y used in the production process of sector i of economy x, we need to disaggregate it using the investment proportion vector of each economy, i.e. $d_{ij}^{xy} m_j^y = d_i^x \sigma_j^{xy}$, where σ_j^{xy} represents the proportion of total investment in economy x spent on products from sector j of economy y. Thus, we can calculate the total value of each sector in different economies under the assumption of complete non-substitutability. By comparing this to the total market price of each sector, we can determine the total value transferred in that sector of the economy.

(2) Value transfer under the assumption of complete substitutability (narrow measure)

Under the assumption of complete substitutability, we must obtain the input–output relationships for the n sectors worldwide, given that there are only n sectors worldwide, where the input–output relationship for each sector reflects the average technological level internationally. Consequently, we derive the socially necessary labor time for each sector as follows:

$$\left(A^\zeta + D^\zeta\right)\lambda^\zeta + l^\zeta = \lambda^\zeta$$

We use superscripts ζ to denote the technical relationships in the entire global market under the assumption of complete substitutability, where A^ζ and D^ζ are matrices $(n \times n)$, representing the coefficient matrices of intermediate input and the depreciation of fixed capital under the average global technical conditions, respectively, and l^ζ a vector of dimension n, representing the coefficient vector of direct labor input under normal global technical conditions. Obviously, A^ζ, D^ζ and l^ζ represent physical relationships, which are not directly attainable in a value-based input–output table but can be solved by using monetary metrics. Let $a_{ij}^\zeta m_j^\zeta = \sum_x \sum_y a_{ij}^{xy} m_j^y$, $d_{ij}^\zeta m_j^\zeta = \sum_x \sum_y d_{ij}^{xy} m_j^y$, and $l_i^\zeta q_i^\zeta = \sum_x l_i^x q_i^\zeta$, then $a_{ij}^\zeta = \sum_x \sum_y a_{ij}^{xy} m_j^y / m_i^\zeta$, $d_{ij}^\zeta = \sum_x \sum_y d_{ij}^{xy} m_j^y / m_i^\zeta$ and $l_i^\zeta = \sum_x l_i^x q_i^x / m_i^\zeta$ [2]. Thus, we have

$$\left(A^\zeta + D^\zeta\right)\lambda^\zeta + l^\zeta = \lambda^\zeta \tag{12}$$

Thereby, the global value vector λ^ζ is obtained under the assumption of complete substitutability. Additionally, similar to the previous method, since we only have aggregate data for each sector in terms of the depreciation of fixed capital, we also need to disaggregate it through the investment proportion vector. The disaggregation method is similar: $d_{ij}^\zeta m_j^\zeta = d_i^\zeta \sigma_j^\zeta$ and $d_i^\zeta = \sum_x \sum_y \sum_j d_{ij}^{xy} m_j^y$, where σ_j^ζ represents the proportion of total worldwide investment allocated to purchase the products from sector j.

After calculating the total value of each sector worldwide through the above method, we decompose the value amount into the total value produced by each economy in that sector based on the proportion of output each economy contributes to that sector, and by comparing this with the total market price, we can determine the total of value transferred.

3.2 Calculation of ecologically unequal exchange

The approach for calculating ecologically unequal exchange is similar to the method used for calculating value transfer but simpler. Let us consider the difference between the total environmental costs that an economy puts into production and the environmental costs of final consumption. Evidently, the larger this discrepancy, the more likely the economy is to be adversely affected by ecologically unequal exchange (Moran *et al.*, 2013; Yu *et al.*, 2014). The calculation of the total environmental cost input is similar to that of the total value, which can be defined as the following equation:

$$(A + D)e + f = e \tag{13}$$

where f denotes the vector of direct environmental cost input, which may be any type of environmental input such as energy, land, water resources or carbon emissions, e the vector of total environmental inputs, which likewise can be any type of environmental cost.

Obviously, we can easily extend this to an international scope with $(A^{\tau} + D^{\tau})e^{\tau} + f^{\tau} = e^{\tau}$. Furthermore, to align with the input–output table, we must convert the equation from the physical form to a monetary form:

$$(A^{\tau} + D^{\tau})e^{\tau} + f^{\tau} = \lambda^{\tau} \tag{14}$$

where $f_i^x = f_i^x q_i^x / m_i^x$. From equation (14), we can derive e^{τ} and, subsequently, determine the total environmental cost input for different sectors within each economy. By aggregating the total environmental cost inputs in all sectors within an economy, we obtain the total environmental cost inputs of an economy. We can find out the final consumption of a certain type of environmental cost of economy x, denoted as ϕ^x, by simply multiplying h^x, the final consumption vector of products in economy x by e^{τ}. The element h_i^y of h^x represents the number of products from sector i in economy y consumed by economy x, measured in monetary value. In this way, we can calculate the ratio between the environmental cost consumed by an economy and the environmental cost input in the economy, thereby obtaining an appropriate measure of ecologically unequal exchange.

4. Construction of the econometric model and data description

4.1 Econometric model

The following two sections use regression analysis to discuss the relationship between value transfer and ecologically unequal exchange. For this purpose, we utilize the World Input-Output Database (WIOD) (Dietzenbacher *et al.*, 2013) to calculate the degrees of ecologically unequal exchange and value transfer of 40 economies over 15 years from 1995 to 2009. The econometric model is as follows:

$$Eue = \beta_0 + \beta_1 vt + \gamma_j CX + \delta_{\sigma} + \delta_t + \mu \tag{15}$$

where Eue denotes the degree of ecologically unequal exchange, which is the core dependent variable and can be calculated through the method described in the third section based on WIOD data. This calculation method is applicable to any environmental cost. We regard the degree of ecologically unequal exchange in carbon dioxide emissions as the dependent variable in the main regression analysis. The degree of ecologically unequal exchange regarding water resource input is the dependent variable in the subsequent robustness check.

The degree of value transfer is denoted as vt, defined as the ratio of total value to total market price. A higher vt indicates a greater impact of unequal exchange on the economy. Subsequently, we conduct regressions on the degree of value transfer calculated under two different assumptions. Both of which can be computed using the WIOD data.

The vector of control variables is denoted as CX. As previously discussed, the ecologically unequal exchange is also affected by other factors. Drawing on existing literature (Jorgenson, 2009; Li and Qi, 2011; Jing and Zhang, 2014), we primarily control for the following factors:

(1) The logarithm of gross domestic product (GDP) per capita ($\ln gdp$) and its square term ($\ln gdp^2$)

According to the logic of the EKC, the level of economic development can affect the eco-efficiency of an economy's production through its technical efficiency and industrial structure, and thus its degree of ecologically unequal exchange. This effect may be in an inverted U-shape.

(2) The degree of economic openness (*open*)

We measure the degree of economic openness by the ratio of total imports and exports to GDP. Ecologically unequal exchange is a process that relies on the global market. Economies deeply integrated into the global market and relatively closed ones should exhibit different degrees of ecologically unequal exchange under similar conditions.

(3) The rate of urbanization (*urban*)

We measure the degree of urbanization by the proportion of the urban population to the total population. Urban and rural areas exert different pressures and have different demands on the environment. Furthermore, the process of urbanization can alter the industrial structure of an economy. All of them may affect the input and consumption regarding the environmental costs of the economy.

(4) Labor quality (*education*)

We measure the average quality of the labor force using high school enrollment rates. Labor quality can potentially impact an economy's technical efficiency, industrial structure, implementation of environmental protection policies and the formation of ecological awareness, thereby influencing the economy's environmental cost input and consumption.

(5) The logarithmic values of average temperature ($\ln temp$) and average precipitation ($\ln precip$)

The natural conditions represented by the climatic factors of an economy can impact the technical and ecological efficiency of its production processes and its consumption behaviors, thereby affecting the amount of environmental cost it uses. Therefore, we control for climate factors by using the logarithmic values of average temperature and average precipitation as control variables.

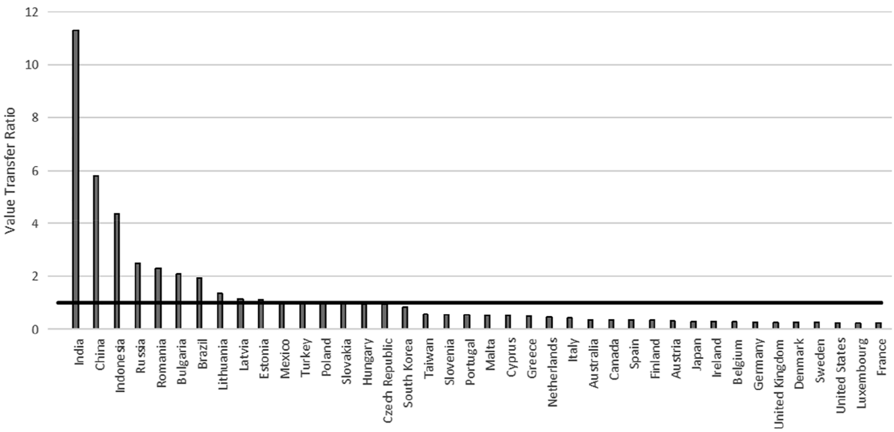
The data for the control variables mentioned above, i.e. GDP per capita, the ratio of total imports and exports to GDP, the proportion of the urban population to the total population and the high school enrollment rate, are sourced from the World Bank. The data for average temperature and precipitation are sourced from Weather.org.

The fixed effects of region and time are denoted by δ_σ and δ_t, respectively, controlling for the unobservable factors regarding region and time.

4.2 A preliminary description of value transfer and ecologically unequal exchange

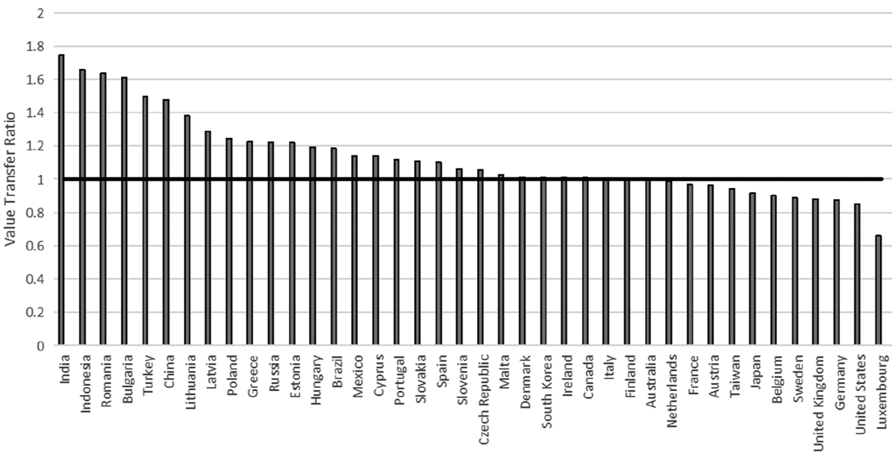
After identifying the main explanatory variables, dependent variables and control variables, our primary objective is to determine whether the main explanatory variables and the dependent variables align with theoretical expectations, i.e. developed economies act as value recipients while developing economies serve as value transferors; furthermore, developed economies benefit from ecologically unequal exchange and developing economies are disadvantaged by it.

Figures 1 and 2 exhibit the degree of value transfer of economies calculated under two different measures, respectively, and ranked the economies from highest to lowest. Figure 1 is based on the assumption of complete non-substitutability between sectors, while Figure 2 assumes complete substitutability between sectors. These figures show that regardless of the measure used to calculate value transfer, developing economies in Asia, Latin America and Eastern Europe exhibit a higher ratio of the total value to total market price, which exceeds 1, identifying them as net value-transferring regions, while most developed regions display relatively low ratios less than 1, categorizing them as net value-receiving regions. Overall, the



Note(s): The horizontal line in the figure indicates the threshold where the value transfer ratio equals 1
Source(s): The author calculated the results based on the WIOD database

Figure 1. Value Transfer ratio: broad measure (1995–2009 average)



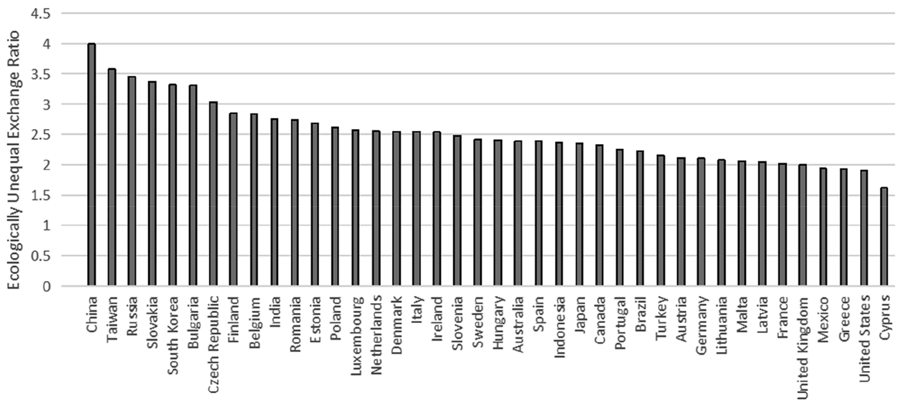
Note(s): The horizontal line in the figure indicates the threshold where the value transfer ratio equals 1
Source(s): The author calculated the results based on the WIOD database

Figure 2. Value Transfer ratio: narrow measure (1995–2009 average)

ranking of economies does not significantly differ between the two calculation methods, with only a few economies changing positions. However, there is a substantial disparity in the numerical values of the degree of value transfer calculated under the two measures, as expected.

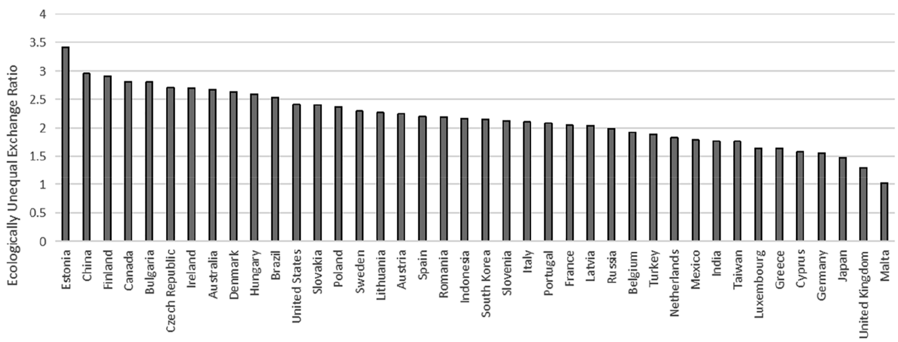
Figures 3 and 4 illustrate the degree of ecologically unequal exchange in terms of carbon dioxide emissions and water resources for 40 economies from 1995 to 2009, ranked by magnitude, respectively. It can be observed that, firstly, most developing economies in Asia and Eastern Europe remain on the disadvantaged side of ecologically unequal exchange, while the most developed capitalist economies occupy an advantaged position. This pattern is analogous to the situation of value transfer.

Secondly, compared with the value transfer, the relation between the rankings of the degree of ecologically unequal exchange and the positions of global northern and southern economies is not strictly correlated. Although relatively less developed economies predominantly face disadvantages in ecologically unequal exchange, many developed economies are also adversely affected, while many developing economies benefit from such exchanges. As previously discussed, ecologically unequal exchange is influenced by numerous factors, particularly industrial structure. We note that most developing economies disadvantaged by



Source(s): The author calculated the results based on the WIOD database

Figure 3. Degree of ecologically unequal exchange regarding CO_2 (1995–2009 average)



Source(s): The author calculated the results based on the WIOD database

Figure 4. Degree of ecologically unequal exchange regarding water resources (1995–2009 average)

ecologically unequal exchange are undergoing rapid industrialization, while many of those benefiting have relatively low levels of industrialization. Consequently, the environmental pressures exerted by the production systems of these two types of economies differ significantly. Similar dynamics are observed with other actors. Therefore, establishing the relationship between value transfer and unequal exchange requires the use of adequate control variables.

5. Empirical analysis

5.1 Baseline regression: ecologically unequal exchange of CO_2 emissions

Table 1 presents the regression results with the degree of ecologically unequal exchange in terms of CO2 emissions as the dependent variable. Columns (1) to (3) use the broad measure of the degree of value transfer (*vt*1) as the main explanatory variable, while columns (4) to (6) employ the narrow measure of the degree of value transfer (*vt*2).

In terms of method selection, we adopt the model through ordinary least squares (OLS) estimation as the baseline reference model and correct the standard errors of the OLS coefficients based on heteroskedasticity-robust standard errors. We employ a regional fixed-effects model (FE1) to control for fixed effects between regions and use a two-way fixed-effects model (FE2) to further control for both regional and temporal fixed effects, forming a set of regression models from simple to complex to ensure the reliability of the regression methods and results. We conduct three regressions for each of the two main explanatory variables: pooled OLS, the FE1 and the FE2. Due to significant multicollinearity issues between the degree of value transfer under the narrow measure and both the logarithm of GDP per capita and its squared term, it is infeasible to address these under OLS conditions.

Table 1. Regression of ecologically unequal exchange of CO_2 emissions

Variables	(1) OLS	(2) FE1	(3) FE2	(4) OLS	(5) FE1	(6) FE2
*vt*1	0.024***	0.018***	0.021***			
	(0.006)	(0.004)	(0.004)			
*vt*2				0.103***	0.128***	0.143***
				(0.019)	(0.023)	(0.023)
ln *gdp*	0.224**	0.360***	0.504***		0.145***	0.225***
	(0.107)	(0.096)	(0.107)		(0.056)	(0.062)
ln gdp^2	−0.012**	−0.020***	−0.029***		−0.008***	−0.014***
	(0.005)	(0.005)	(0.006)		(0.003)	(0.004)
open	0.023***	0.039***	0.037***	0.021***	0.041***	0.039***
	(0.006)	(0.013)	(0.013)	(0.006)	(0.013)	(0.013)
urban	0.076***	0.404***	0.244***	0.005	0.367***	0.224***
	(0.027)	(0.060)	(0.078)	(0.029)	(0.057)	(0.076)
education	0.000	0.012	−0.011	0.000	0.032*	0.014
	(0.0002)	(0.019)	(0.020)	(0.0002)	(0.017)	(0.018)
ln *temp*	−0.077***	−0.051***	−0.016	−0.071***	−0.083***	−0.092***
	(0.007)	(0.012)	(0.016)	(0.007)	(0.005)	(0.006)
ln *precip*	0.070***	0.074*	−0.081	0.082***	0.245***	0.314***
	(0.010)	(0.042)	(0.066)	(0.012)	(0.030)	(0.038)
Constant term	−0.840	−1.684***	−1.134	0.061	−1.903***	−2.497***
	(0.568)	(0.610)	(0.700)	(0.104)	(0.364)	(0.391)
Sample size	524	524	524	524	524	524
R^2	0.335	0.916	0.919	0.270	0.919	0.922

Note(s): Values in parentheses represent standard errors. The symbols *, **, *** denote significance levels of 10%, 5%, and 1%, respectively
Source(s): Authors' own work

Consequently, we have removed the logarithm of GDP per capita and its squared term from the set of explanatory variables in column (4). From Table 1, we can draw the following conclusions:

First, using both narrow and broad measures of value transfer, the regression coefficients are significantly positive at the 1% level across three regression methods: OLS, regional fixed effects and two-way fixed effects, which substantiates our primary hypothesis: ecologically unequal exchange occurs when value transfer takes place, indicating a strong connection in reality between the two phenomena.

Second, the coefficient estimators of ln *gdp* are consistently positive across all regressions, and the coefficient estimators of ln *gdp* [2] are significantly negative, suggesting the presence of an inverted U-shaped relationship between ecologically unequal exchange and per capita GDP. This finding remains valid even after controlling for value transfer, indicating that the EKC also has explanatory power for ecologically unequal exchange. Hence, the theory of environmental unequal exchange is not merely a substitute for the EKC, contrary to the belief of many eco-Marxists. An economy's ecological pressure is related both to the value transfer within the capitalist world system and to the economy's stage of development.

Third, other control variables are generally significant across different regressions, align with theoretical expectations and exhibit relative stability. The degree of openness to international markets is positively correlated with ecologically unequal exchange, indicating that the deeper an economy engages with the global market, the greater its exposure to ecologically unequal exchanges. This conclusion is evident given that ecologically unequal exchange inherently relies on the international division of labor and trade. The higher the rate of urbanization, the higher the degree of ecologically unequal exchange may be. Because urbanization is intrinsically linked to industrialization, the expansion of human alteration of natural environments and infrastructure not only enhances the environmental pressure exerted by production systems but also increases the proportion of intermediate goods relative to final goods, consequently increasing the environmental costs spent on intermediate goods and further the ratio of environmental cost inputs to final environmental cost consumption. The coefficients on the logarithm of the average annual temperature over the years are all negative and, in most cases, significant, indicating that warmer economies have lower degrees of ecologically unequal exchange. Meanwhile, the coefficient estimators of the logarithm of the average annual precipitation suggest that regions with less rainfall tend to have lower degrees of ecologically unequal exchange. The only difference from the theoretical expectations is that labor quality does not significantly impact the ecologically unequal exchange, and higher educational attainment does not necessarily result in lower degrees of ecologically unequal exchange.

5.2 Robustness check: ecologically unequal exchange of water resources

According to the theory presented in the second section, the relationship between ecologically unequal exchange and value transfer does not depend on the type of environmental cost input involved. Therefore, our conclusion regarding the relationship between CO_2 emissions-based ecologically unequal exchange and value transfer should hold true when other environmental variables are considered. To test this, we replaced the dependent variable — ecologically unequal exchange regarding CO_2 emissions — with ecologically unequal exchange regarding water resources (see regression results in Table 2). If the results remain consistent, this would indicate that our empirical findings are robust and reliable.

Table 2 demonstrates that, except for the coefficient on value transfer in the pooled OLS model of value transfer under the broad measure, which is not statistically significant, the coefficients for value transfer in the other five regressions are significantly positive at the 1% level. This indicates that the positive relationship between value transfer and ecologically unequal exchange persists even when carbon dioxide emissions are replaced with water resource inputs. This finding further corroborates the relationship between ecologically unequal exchange and value transfer.

Table 2. Regression of ecologically unequal exchange of water resources

Variables	(1) OLS	(2) FE1	(3) FE2	(4) OLS	(5) FE1	(6) FE2
*vt*1	0.021	0.121***	0.122***			
	(0.043)	(0.040)	(0.041)			
*vt*2				0.465**	0.616***	0.711***
				(0.183)	(0.206)	(0.213)
ln *gdp*	0.767	5.592***	4.986***	0.544**	3.846***	3.217***
	(0.836)	(0.991)	(1.087)	(0.256)	(0.626)	(0.689)
ln gdp^2	−0.046	−0.281***	−0.237***	−0.030**	−0.190***	−0.140***
	(0.042)	(0.051)	(0.058)	(0.013)	(0.034)	(0.040
open	−0.121**	0.228**	0.267***	−0.100*	0.236**	0.276***
	(0.053)	(0.093)	(0.096)	(0.053)	(0.093)	(0.096)
urban	−0.402*	1.429**	1.981**	−0.339*	1.221*	1.909**
	(0.208)	(0.659)	(0.814)	(0.197)	(0.660)	(0.813)
education	0.308**	−0.578***	−0.584***	0.323**	−0.467***	−0.446**
	(0.135)	(0.167)	(0.182)	(0.136)	(0.167)	(0.179)
ln *temp*	−0.503***	0.857***	0.216	−0.504***	0.881***	0.0786
	(0.046)	(0.324)	(0.491)	(0.044)	(0.323)	(0.491)
ln *precip*	0.060	2.497***	0.607	0.111**	3.078***	0.804
	(0.056)	(0.772)	(1.297)	(0.056)	(0.768)	(1.298)
Constant term	0.100	−45.010***	−29.550**	−0.124	−41.230***	−23.310**
	(4.405)	(7.592)	(11.820)	(1.576)	(7.164)	(11.030)
Sample size	524	524	524	524	524	524
R^2	0.260	0.843	0.848	0.268	0.843	0.849

Note(s): Values in parentheses represent standard errors. The symbols *, **, *** denote significance levels of 10%, 5% and 1%, respectively
Source(s): Authors' own work

The insignificance of the coefficient on value transfer in the pooled OLS model under the broad measure may be attributed to two factors: strong multicollinearity between value transfer and the logarithm of GDP per capita (with a variance inflation factor exceeding 100) and the omitted-variable bias due to the absence of controlling for fixed effects. By comparing the regression outcomes, we observe that the regression results from the two fixed effects are quite similar, while the results from OLS mostly differ from those of the fixed effects, indicating that the OLS model might suffer from substantial omitted variable bias. Therefore, we primarily focus on the regression results from both types of fixed effects. The insignificance of the OLS coefficient under the broad measure does not affect the overall estimation results.

The coefficients on the logarithm of GDP per capita and its square term are both significant under the two fixed-effects models and maintain the same signs as those in the main regression results. The positive coefficient on the logarithm of GDP per capita and the negative coefficient on the squared term indicate that the ecologically unequal exchange of water resources also has an inverted U-shaped relationship with GDP per capita. The degree of openness to international markets and the urbanization rate are significant in results other than the OLS regression and maintain the same signs as those in the main regression results. The amount of precipitation is consistent with the main regression results in the FE1.

Unlike the main regression results, the coefficient on labor quality is significantly negative, suggesting that improving labor quality can considerably reduce the degree of ecologically unequal exchange of water resources. This may be related to the fact that the primary consumption of water resources comes from agriculture, and since agriculture in the major developing economies among the sample is operated by individual agricultural laborers, improving the quality of these laborers can more directly improve the efficiency of water use in agriculture, reduce the cost of water per unit of product, and thus reduce the degree of ecologically unequal exchange. Another difference from the main regression results is the coefficient on the logarithm of temperature, of which estimators indicate that higher temperatures are associated with higher degrees of ecologically unequal exchange. This is intuitive, as regions with higher temperatures generally experience higher evaporation levels, which can lead to an increase in overall water usage. However, once time-fixed effects are controlled for, the coefficient is no longer statistically significant, although the direction of the coefficient remains unchanged. Therefore, it is difficult to draw definitive conclusions regarding the impact of different climates on the ecologically unequal exchange in terms of water resources based on the current results.

6. Conclusion

This paper employs the concept of ecologically unequal exchange to explain the growing ecological disparities between developing and developed countries. It also connects ecologically unequal exchange with traditional theories of unequal exchange and value transfer. By constructing a two-sector, two-economy Okishio-Morishima model, we demonstrate that the high organic composition of capital and high real wages in developed economies can lead to international value transfer under fairly relaxed conditions and similarly lead to ecologically unequal exchange under analogous conditions. Subsequently, we used WIOD data to calculate the degrees of value transfer and ecologically unequal exchange for 40 economies from 1995 to 2009 and verified their relationship using regression analysis.

The existence of ecologically unequal exchange indicates that the increasing consumption of resources and environment in developing countries is not solely a consequence of their factors, such as the degree of regulation, developmental stages or technological levels, as the developed economies also play a significant role in this process. When developed economies import products from developing economies at very low prices, they exchange lower environmental costs for higher environmental cost inputs of developing economies. It can be said that through ecologically unequal exchange, developed economies transfer their regional environmental costs to developing economies. Consequently, developed economies should be held accountable for the high greenhouse gas emissions, high energy consumption and high pollution prevalent in many developing economies today.

The relationship between ecologically unequal exchange and value transfer indicates that the mechanism of transferring environmental costs is deeply rooted in the production structure of the capitalist world system. As long as developed countries have a higher organic composition of capital and wages, value transfer and ecologically unequal exchange can occur on the global market, even in perfect competition. The higher organic composition of capital and high wages are also the results of the accumulation process in the capitalist world system, particularly with the trend towards higher capital intensities being self-reinforcing, which implies that value transfer and ecologically unequal exchange are also self-reinforcing. As long as the production structure of the capitalist world system remains unchanged, developing economies will find it challenging to break free from the pattern of bearing the environmental burden for the production of goods consumed by other countries, and hence, it will be difficult for them to improve their ecological environment fundamentally.

This is particularly evident in China. As demonstrated by the data presented in Section 4, China exhibits a significantly higher level of ecologically unequal exchange compared to other economies in the sample. This phenomenon is closely intertwined with China's reliance on inexpensive labor and environmental degradation for exporting cheap goods within the current global production system. Consequently, while the volume of exports has surged, environmental challenges have simultaneously intensified. These environmental issues are not solely a domestic concern of China but are inherently linked to the global economic production structure and cycle. Therefore, addressing these environmental concerns necessitates that China both advances its economy towards a more advanced stage of development with an optimized division of labor and a rational economic structure, as well as actively engages in global governance to reform the inequitable traditional international economic order, thereby gradually resolving its environmental problems.

Notes

1. The other root for the relative price, $p = [(c_{11} - c_{22}) - \sqrt{4c_{12}c_{21} + (c_{11} - c_{22})^2}]/2c_{21}$ is omitted because it has no economic significance as it is negative due to $\sqrt{4c_{12}c_{21} + (c_{11} - c_{22})^2} > c_{11} - c_{22}$.
2. In this context, the same coefficient is aggregated on a global scale, following the general logic of input–output table aggregation (Feng, 2016b).

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