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Comparing Production- and Consumption-based CO_2 Emissions by Economic Growth*

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Jooman Noh
Department of Economics, Dankook University, South Korea

Hong Chong Cho†
Department of Economics, Dankook University, South Korea

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Abstract

Purpose – Carbon emission standards are based on the "production-based carbon emissions" generated by the production of goods in the relevant country which were the existing measurement methods. However, can such carbon emissions measurement standards be established international? For example, some of the goods produced in developing countries are produced for the demand of developed countries. The method of measuring carbon emission based on the final demand of a certain country is called "consumption-based carbon emissions." This study compares production- and consumption-based CO_2 emissions according to economic growth in ninety-three countries categorized by income level.

Design/methodology – Our empirical model considers the difference between production- and consumption-based CO_2 emissions according to economic growth. Also, our model investigated whether the EKC hypothesis in most of the previous studies that had been based on production-based emissions was also established in the consumption-based emission model. Considering the continuous characteristics of CO_2, we utilized the generalized method of moments (GMM), specifically a system GMM econometric technique because CO_2 in the previous period can affect CO_2 in the present period.

Findings – Our main findings can be summarized as follows: The results show that for the consumption-based CO_2 emissions model, CO_2 continuously increases as economic growth increases in the upper-middle income countries. The inverted U-shaped result was found in the case of the production-based model. However, in the lower-income countries, an inverted-U shape in which CO_2 emissions decrease at some point as the economy grows in the production-based model does not appear. On the other hand, in the consumption-based model, an inverted U-shaped result was obtained when estimating with system-GMM. Additionally, the proportion of manufacturing, energy imports, and energy consumption had an effect on both the production- and the consumption-based model regardless of the group's CO_2 emissions. On the basis of such assessments, policymakers need to consider not only production- but also consumption-based options.

Originality/value – Previous studies have mainly focused on production-based CO_2 emissions, with most of them revolving around economic growth or the effect of various social and economic factors on CO_2 emissions. However, this study considers the relationship with economic growth using consumption-based emissions as a dependent variable by classifying ninety-three countries by income level.

Keywords: Carbon Leakage, Consumption-based CO_2 Emissions, Economic Growth, Production-based CO_2 Emissions
JEL Classifications: F18, O13, Q56

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† **Corresponding author:** hongcho@dankook.ac.kr

1. Introduction

Most countries are interested in the on-going climate crisis and global warming and are suggesting policies for it. Accordingly, many countries are insisting on decarbonization, but some countries still maintain high-carbon emission industries, continuing with carbon emissions.

A total of 195 countries have agreed to work together to keep the increase in global average temperature below 2°C before industrialization and to limit it to 1.5°C in the Paris Agreement in 2015. As of April 2022, 18 countries have legislated carbon neutrality and 70 countries have been documented as policies[1].

Carbon emission standards are based on the “production-based carbon emissions” generated by the production of goods in the relevant country. However, can such carbon emissions measurement standards be established international? For example, some of the goods produced in developing countries are produced for the demand of developed countries. If so, is it right for the third country to take full responsibility for the carbon emissions it generates? The method of measuring carbon emission based on the final demand of a certain country is called “consumption-based carbon emissions.”

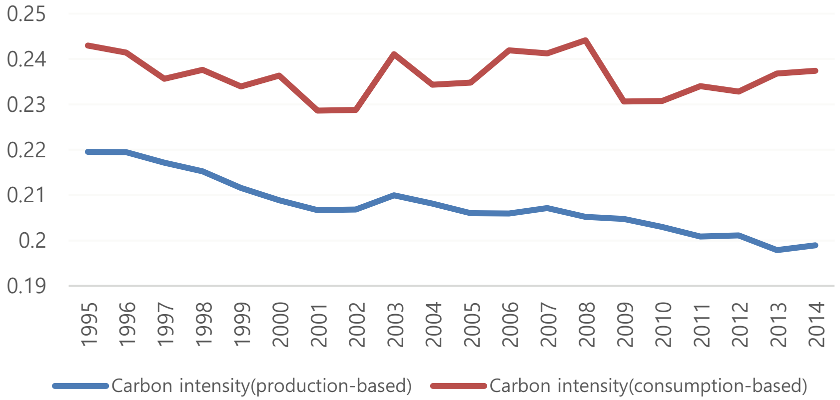
Discussions on such consumption-based emissions have been steadily presented since many years (Barrett et al., 2013; Kondo, Wilting and Vringer, 2009; Lenzen, Dey and Foran, 2004; Mi et al., 2016; Moriguchi and Shimizu, 1998; Södersten, Wood and Hertwich, 2018; Subak, 1995). Therefore, we need to analyze consumption-based emissions alongside production-based emissions that have been previously used. Most recent studies have focused on production-based emissions and analyzed the factors that affect production-based carbon emissions from an overall perspective or how finance, science, and technology affect production-based carbon emissions from a microscopic perspective (Balogh and Jámbor, 2017; Hanif et al., 2019; Muhammad and Long, 2021; You and Lv, 2018).

However, as these studies are based on production-based emissions, they have limitations that do not reflect carbon leakage that transfers production activities to neighboring countries with low carbon emission regulations. We calculated the carbon intensity to find out. Carbon intensity is the amount of carbon dioxide (CO_2) emissions compared to energy consumption, and each data used was provided by Our world in data (OWID). The trends of production- and consumption-based CO_2 emissions in the upper-middle income countries and lower-middle income countries in the following figures are suspicious of carbon leakages. The production-based CO_2 emissions of upper-middle countries have steadily decreased, while the consumption-based CO_2 emissions have not decreased. Moreover, the correlations of each group country are 0.346 and 0.871, respectively. In other words, the upper-middle countries experienced production-based CO_2 and consumption-based CO_2 decoupling, but the lower-middle countries experienced coupling.

Existing studies have primarily proved the environmental Kuznets curve (EKC) hypothesis through empirical analysis, finding that carbon emissions decrease at a certain point in time as the economy grows (Ali et al., 2021; Dogan and Inglesi-Lotz, 2020; Wang and Donghui, 2022). However, because previous studies are a standard for production-based emissions, it is necessary to examine whether the EKC hypothesis is confirmed in consumption-based emissions based on the final demand of a country.

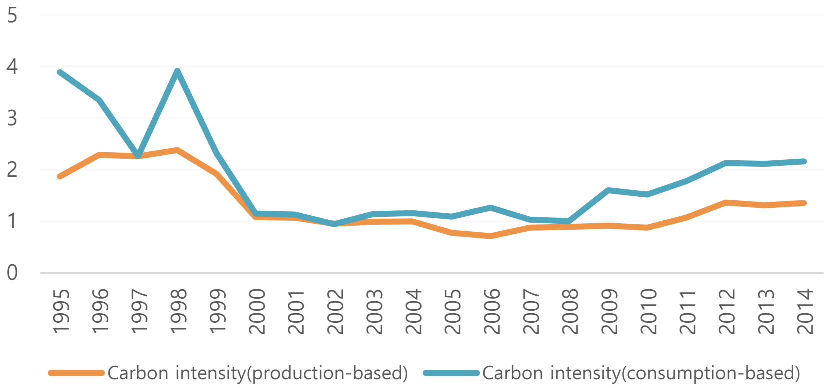
[1] Net Zero Tracker, https://zerotracker.net/

Fig. 1. Evolution of Upper-middle Income Countries Carbon Intensity, 1995-2014



Source: Authors' calculation using OWID data.

Fig. 2. Evolution of Lower-middle Income Countries Carbon Intensity, 1995-2014



Source: Authors' calculation using OWID data.

Although studies have been conducted on consumption-based emissions, ones that directly calculate consumption-based emissions using the embodied in bilateral trade (EEBT), multi-regional input–output (MRIO), and input–output (I-O) tables methodologies have been predominant (Munksgaard and Pedersen, 2001; Peters, Davis and Andrew, 2012). Therefore, rather than directly calculating consumption-based emissions, this study derives its results through a quantitative model, such as the methodology used in existing production-based studies. Furthermore, it is meaningful to examine the differences by comparing and analyzing the relationship between production-based emissions and economic growth conducted in previous studies with consumption-based emissions. Therefore, the results of this study are to examine the differences in production- and consumption-based by dividing as many countries by income as possible.

Based on this awareness, this study intends to analyze the relationship with economic growth based on consumption-based emissions.

This study investigated whether the EKC hypothesis in most of the previous studies that had been based on production-based emissions was also established in the consumption-based emission model. As per the EKC hypothesis, carbon emissions also increase as a country's economy grows; however, after peaking at a certain point, carbon emissions decrease even as the economy grows. In other words, long-term economic growth and having a clean environment do not collide. Existing studies have proven through empirical analysis that the EKC hypothesis is established through technological development and industrial structure changes, such as post-industrialization, when countries become developed at some point after economic growth.

However, for consumption-based emissions, this means that as the economy grows, it will turn into a service-structured industry. In other words, it may appear that the country's carbon is decreasing through carbon leakage rather than reducing carbon emission by changing to an industrial structure that reduces carbon emission and reduces consumption.

To clearly distinguish them, this study conducted an empirical study through consumption-based emissions. In production-based emissions, we examined whether an inverted U-shape, in which carbon emissions decrease as the economy grows, or whether these results is derived from consumption-based emissions. Regarding consumption-based emissions, we believe that this study is meaningful in that by categorizing as many countries as possible by income, it is possible to see the difference in the relationship between economic growth and CO_2 in the production- and the consumption-based model.

The rest of this paper is organized as follows. Chapter 2 presents a literature review of production- and consumption-based emissions. Chapter 3 presents the data of production- and consumption-based emissions in ninety-three countries. Chapter 4 presents the results of production- and consumption-based emissions. Finally, Chapter 5 summarizes the research results and presents policy implications.

2. Literature Review

2.1. Production-based CO_2 Emissions Determinants

Generally, studies related to the determinants of CO_2 emissions are mostly production-based and were analyzed in various regions, income standards, political systems, finance, science and technology, and other industrial aspects. In particular, alongside the above factors, many studies empirically study the EKC hypothesis that examines the relationship between economic growth and CO_2 emissions.

Muhammad and Long (2021) analyzed the effect of institutions such as politics, corruption index, and law compliance on CO_2 according to countries' income. Institutional factors were found to play key roles in carbon emission and environmental improvement. Additionally, Bakhsh, Yin and Shabir (2021), and Omri, Nguyen and Rault (2014) studied the effect of investment such as foreign direct investment (FDI) on CO_2. In particular, Bakhsh et al. (2021) analyzed the relationship between technological innovation and institutional quality with foreign investment and CO_2 emissions in 40 Asian countries, finding that although FDI alone had a positive effect on CO_2 emission, it was possible to reduce CO_2 emission when technological innovation factors or institutional improvements were combined. Meanwhile, the change of CO_2 according to international trade differed according to the development level of the country (Antweiler, Copeland and Taylor, 2001; Frankel and Rose, 2005; Le, Chang and Park, 2016). Moreover, there are many studies on the effect of energy imports on CO_2 (Tamazian, Chousa and Vadlamannati, 2009; Tamazian and Rao, 2010; Aller, Ductor and Grechyna, 2021). Specifically, Tamazian, Chousa and Vadlamannati (2009) argued that net energy imports had a positive effect on CO_2 emission. This is because energy-intensive countries imported a lot of energy.

Haseeb et al. (2018), Mahmoud et al. (2021), Tamazian, Chousa and Vadlamannati (2009) showed that the EKC hypothesis was established, but Ahmed, Rehman and Ozturk (2017) studied South Asian countries and found that EKC did not exist. The EKC hypothesis tends to be established mainly in developed countries (Leal and Marques, 2020). However, it is important not only to look at these effects only in the production-based model, but also to analyze the factors that ultimately affect carbon emissions through differences from the consumption-based model.

2.2. Consumption-based CO_2 Emissions

Studies on consumption-based emissions have been studied while pointing out the problem of carbon leakage and the limitations of existing production-based emissions (Davis and Calderia, 2010; Rocco et al., 2020). In general, production-based emissions are calculated as carbon emissions within a country's territory, and consumption-based emissions are calculated by subtracting carbon emissions from exports from production-based emissions and adding carbon emissions from imports; that is, Consumption = Production – Exports + Imports (Peters, Davis and Andrew, 2012). Consumption-based accounting has been mainly conducted through MRIO, EEBT methods, and it has presented a new perspective on the method of estimating carbon based on a country's demand (Hertwich and Peters, 2009; Karstensen, Peters and Andrew, 2018). EEBT considers domestic emission intensity and total trade flows, while MRIO considers trade only as final consumption of global emission intensity.

Kanemoto et al. (2012), Peters, Davis and Andrew (2012) derived consumption-based CO_2 through MRIO and EEBT methods using the international trade flow table and revealed that MRIO is more efficient in calculating final demand. Since the MRIO and EEBT models have the same output, the carbon emissions from production are the same in the two models. However, since the MRIO model divides export goods into the final demand use and the intermediate input use of the trading partner, the carbon emissions contained in consumption differ.

There are not only methods that account for these consumption-based emissions but also papers that have recently investigated their relationship with economic growth. Rahman et al. (2022) analyzed consumption-based accounting of the South Asian Association for Regional Cooperation region and linked it with sustainable development goals. Consequently, a clear causal relationship could not be elucidated. Pandey, Dogan, and Taskin (2020) and Qin et al. (2021) studied the relationship between consumption-based carbon emissions and economic growth. The former was for Asian countries and the latter for Next Eleven (N-11) countries. In both studies, the EKC hypothesis was established in the production-based model, but not in the consumption-based emission model.

Considering the literature review, the hypotheses for the study are as follows. First of all, our main objective is to verify comparing production- and consumption-based CO_2 emissions by economic growth. Therefore, we set CO_2 emission as an independent variable, set the GDP variable and the square term of GDP as the explanatory variable, and added five explanatory variables to set it as a control variable. In addition, we classified the various countries by income level. We expect that in the upper-middle income countries, CO_2 emissions increase as GDP per capita increases in the production-based model and then peak and decrease at some point, but in the consumption-based model, CO_2 emissions continue to increase as GDP per capita increases (Al-Mulali et al., 2015; Qin et al., 2021). However, we expect that in the lower-middle income countries, as GDP per capita increases in the production-based model, CO_2 emissions increase but do not decrease at some point (Aller, Ductor and Grechyna, 2021). Also, it is expected that the relationship will not be clear in the consumption-based model.

3. Data and Methodology

3.1. Data

This study was conducted on ninty-three countries in 1995-2014 where Table 1 lists the sample countries. We conducted a panel data analysis over 1995-2014 for ninty-three countries. There are several papers that have studied EKC (Churchil et al., 2018; Fujii and Managi, 2013; Isik et al., 2021). Based on previous studies, we set industry, trade openness, FDI, energy imports and energy consumption per capita as control variables, Table 2 presented the data description of the data, and Table 3 presented summary of statistics. The consumption-based CO_2 emission data used in this study was calculated based on the methodology used by Peters et al. (2011). Bhattacharya, Inekwe and Sadorsky (2020) and Qin et al. (2021) also used the data. The data was calculated using the MRIO methodology in the following way.

Table 1. List of Sample Countries Categorized Based on Their Income Level

Upper-middle income countries	Argentina, Australia, Austria, Belgium, Botswana, Brazil, Brunei, Bulgaria, Canada, Chile, China, Colombia, Costa Rica, Croatia, Cyprus, Czechia, Denmark, Dominican Republic, Ecuador, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Israel, Italy, Japan, Kazakhstan, Latvia, Lithuania, Malaysia, Malta, Mauritius, Mexico, Netherlands, New Zealand, Oman, Peru, Poland, Portugal, Romania, Russia, Saudi Arabia, Singapore, Slovakia, Slovenia, South Africa, South Korea, Spain, Sweden, Thailand, Turkey, United Kingdom, United States, Uruguay
Lower-middle income countries	Azerbaijan, Bangladesh, Benin, Bolivia, Cambodia, Cameroon, Cote d'Ivoire, Egypt, El Salvador, Ghana, Guatemala, Honduras, India, Indonesia, Iran, Jamaica, Jordan, Kenya, Kyrgyzstan, Morocco, Mozambique, Nepal, Nicaragua, Nigeria, Pakistan, Paraguay, Philippines, Senegal, Sri Lanka, Tanzania, Togo, Tunisia, Ukraine, Vietnam, Zambia, Zimbabwe

$$\begin{pmatrix} X_1 \\ X_2 \\ \vdots \\ X_m \end{pmatrix} = \begin{pmatrix} A_{11} & A_{12} & \cdots & A_{1m} \\ A_{21} & A_{22} & \cdots & A_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ A_{m1} & A_{m2} & \cdots & A_{mm} \\ & & \cdots & \end{pmatrix} \begin{pmatrix} X_1 \\ X_2 \\ \vdots \\ X_m \end{pmatrix} + \begin{pmatrix} \Sigma_r Y_{1r} \\ \Sigma_r Y_{2r} \\ \vdots \\ \Sigma_r Y_{mr} \end{pmatrix} \quad (1)$$

In equation (1), X_i is the total production of country i, X_{ir} is the production of country i corresponding to the demand of country r, and A_{ir} is the coefficient of intermediate goods produced in the country and responding to the demand of country r. Y_{rr} is the domestic final consumption of country r.

Therefore, the MRIO model can be expressed as follows.

$$X = AX + Y \quad (2)$$

The carbon intensity by industry in country i is called $k = [k_1, k_2, \dots, k_n]$. Therefore, the consumption-based CO_2 emissions can be represented as follows. The inverse matrix $(I - A)^{-1}$ represents input factors for goods and services by country and sector.

$$C = k(I - A)^{-1}Y \quad (3)$$

C represents a vector of total consumption-based CO_2 emissions, embodied in goods and services consumed by the final demand of all countries.

Table 2. Data Description

Variable	Description	Source
lnCO_2	The per capita production-based CO_2 emission (metric tons per capita)	Our world in data
lnCO_2con	The per capita consumption-based CO_2 emission (metric tons per capita)	Our world in data
lnGDP	GDP (GDP per capita, constant 2015 US$)	World Development Indicator
lnGDP^2	Squared GDP per capita	Calculated from GDP per capita
Industry	Industrial structure, industry, value added (% of GDP)	World Development Indicator
Tradeopenness	Total trade as the percentage of GDP	World Development Indicator
FDI	Foreign direct investment, net inflows (% of GDP)	World Development Indicator
Energy imports	Net energy imports (% of energy use)	World Development Indicator
lnEnergycon	Primary energy consumption per capita (MWh)	Our world in data

Table 3. Summary of Statistics

Panel	Variable	Mean	Std. Dev.	Min	Max
Upper-middle income countries	CO_2 per capita	7.8115	4.6308	0.9575	24.2444
	CO_2con per capita	8.8920	5.2722	1.0800	37.7841
	GDP per capita	20186.11	14938.83	1520.027	56305.98
	Industry	29.2884	9.7138	9.9847	74.1130
	Tradeopenness	88.0847	58.4757	15.6356	437.3267
	FDI	6.9973	25.9715	−15.7076	449.0828
	Energy imports	1.1055	135.5126	−849.5552	100
	Energycon	39.9572	26.9075	5.4280	160.1932

Table 3. (Continued)

Panel	Variable	Mean	Std. Dev.	Min	Max
Lower-middle income countries	CO_2 per capita	1.3023	1.5827	0.0661	8.2855
	CO_2con per capita	1.4147	1.4320	0.1186	7.6595
	GDP per capita	1947.963	1286.152	219.1928	5505.988
	Industry	26.6592	8.4984	12.5665	66.1212
	Tradeopenness	70.7103	28.5740	21.9295	169.5345
	FDI	3.4103	5.1086	−5.0882	55.0703
	Energy imports	4.2035	66.5183	−465.4873	96.8123
	Energycon	6.2403	7.5765	0.0156	35.9087

3.2. The Model

Considering the continuous characteristics of CO_2, we utilized the generalized method of moments (GMM), specifically a system GMM econometric technique because CO_2 in the previous period can affect CO_2 in the present period. First, the specific model can be expressed as:

$$\ln CO_{2it} = \beta_0 + \theta \ln CO_{2i,t-1} + \beta_1 \ln gdppc_{it} + \beta_2 \ln gdppc_{it}^{2} + \beta_3 Industry_{it} + \beta_4 Tradeopenness_{it} + \beta_5 FDI_{it} + \beta_6 Energyimports_{it} + \beta_7 \ln Energycon_{it} + \varepsilon_{it} \quad (4)$$

$$\ln CO_2con_{it} = \beta_0 + \theta \ln CO_{2i,t-1} + \beta_1 \ln gdppc_{it} + \beta_2 \ln gdppc_{it}^{2} + \beta_3 Industry_{it} + \beta_4 Tradeopenness_{it} + \beta_5 FDI_{it} + \beta_6 Energyimports_{it} + \beta_7 \ln Energycon_{it} + \varepsilon_{it} \quad (5)$$

where θ is the regression coefficient of a lagged period of the explanatory variable. In Equation (1), the dependent variable is production-based emissions, and GDP per capita and its square term are independent variables to test the EKC hypothesis. Additionally, industrial structure, trade openness, FDI, and energy consumption per capita are control variables, and all are logged. In Equation (2), the dependent variable is consumption-based emissions, and to compare the EKC hypothesis, the independent variable was set similar to Equation (1), and all-natural logarithms were performed in the same way.

For analysis, we applied the system GMM by Arellano and Bover (1995) and Blundell and Bond (1998). First, the GMM is used, which uses lagged variables as instrumental variables, and the basic model is:

$$y_{it} = \alpha + \gamma y_{it-1} + \beta x_{it} + u_i + e_{it} \quad (6)$$

Equation (4) is equivalent to the difference to remove the fixed effect.

$$\Delta y_{it} = \Delta y_{it-1} + \Delta x_{it} \beta + \Delta \varepsilon_{it} \quad (7)$$

To be available as an instrumental variable, there should be no correlation with the error term of the differential expression. However, because the error term at this time is $\Delta\varepsilon_{it} = \varepsilon_{it} - \varepsilon_{it-1}$, y_{it-1} it is not appropriate as an instrumental variable. However, y_{it-2}, y_{it-3}, etc. are not correlated with the error term, but are related to the explanatory variable x_{it} so they may be appropriate as instrumental variables. Thus, after removing the fixed effect by differentiating the model, the method of using the lagged variable of the explanatory variable as an instrumental variable to analyze it using the generalized moment method is called the difference GMM method. Conversely, using the differential lagged variable as an instrumental variable while leaving the model undifferentiated is called level GMM, and using both difference and level GMM information, it becomes system GMM.

4. Empirical Results

We conducted an analysis using system GMM and additionally performed an estimation using feasible generalized least squares (FGLS). The problems of serial correlation and heteroskedasticity can be solved through FGLS model (Maddala and Lahiri, 2006). The FGLS allows models with heteroskedasticity and no cross-sectional correlation (Greene, 2012). Moreover, Rao and Griliches (1969) described that FGLS is more appropriate and efficient than least squares for the big sample size and FGLS can overcome the problems of heteroskedasticity and autocorrelation. However, if time-varying national characteristics exist, the problem of endogeneity remains. Additionally, due to economic growth, etc., CO_2 emissions within the same country may be affected, and endogeneity problems may still occur. Therefore, to improve the accuracy of these measurements and alleviate the endogeneity problem, lagged instrumental variables were introduced and the results are in Table 4 and 5 using two-step system GMM estimation. It is broadly acknowledged that two-step GMM results are more robust as compared to the one-step system GMM.

First, Table 4 shows that the production-based emissions and the variable of GDP per capita have a positive relationship, and the square term variable of GDP per capita has a negative result in the upper-middle income countries. In other words, the inverted U-shaped EKC hypothesis holds that CO_2 emissions increase as the economy grows, then peak, and then decrease. These results complement previous studies.

Furthermore, the larger the total share of industry in total economy, the higher the CO_2 emission. Meanwhile, the relationship between the degree of trade openness and CO_2 emission was negative. A high degree of trade openness enables efficient production according to the domestic situation through comparative advantage, which can lead to an increase in imports and exports. Therefore, the increase in the effect of technology transfer due to trade activation has the effect of accelerating the movement of new technologies and making it easier to introduce eco-friendly technologies. These results can bring environmental improvement effects in the long term (Akin, 2014).

The relationship between FDI variables and CO_2 emissions was positive. According to the pollution haven hypothesis, companies in the uppper-middle income countries move to countries with low environmental regulations to export pollution. Therefore, as FDI increases, more pollution-intensive products produced in other countries are imported than environmentally friendly products produced in their own countries, resulting in an increase in CO_2 emissions. Seker, Ertugrul and Cetin (2015) also investigated the positive relationship between CO_2 emissions and FDI in host countries and how low environmental standards and taxes move some pollution-intensive industries from developed economies to underdeveloped ones. In this regard, host countries become "pollution shelters" and environmental quality deteriorates, suggesting that these industries move to emerging economies to avoid the high environmental costs of origin economies (Zhang and Zhou, 2016).

Table 4. Estimation Results for the Upper-middle Income Countries

Variable	$\ln CO_2$		$\ln CO_2 con$	
	Sys-GMM	FGLS	Sys-GMM	FGLS
L1	0.6046*** (0.0065)	-	0.3285*** (0.0067)	-
lnGDP	0.5250*** (0.1391)	1.3678*** (0.3433)	0.4098* (0.2452)	0.3968** (0.1529)
$\ln GDP^2$	−0.0309*** (0.0074)	−0.0687*** (0.0180)	−0.0164 (0.0128)	−0.0122 (0.0080)
Industry	0.0056*** (0.0003)	0.0065*** (0.0010)	0.0119*** (0.0004)	0.0036*** (0.0008)
Trade openness	−0.0013*** (0.0001)	−0.0007*** (0.0002)	0.00006 (0.00008)	0.0004** (0.0001)
FDI	0.0002*** (0.00002)	0.00004 (0.0001)	−0.0002*** (0.00001)	0.0002 (0.0003)
Energy imports	0.0002*** (0.00002)	0.00008 (0.0001)	0.0002*** (0.00003)	0.0005*** (0.00006)
lnEnergycon	0.4259*** (0.0126)	0.7782*** (0.0271)	0.5037*** (0.0074)	0.7363*** (0.0126)
Constants	−3.1301*** (0.6536)	−7.7824*** (1.6158)	−3.1655** (1.1768)	−3.3600*** (0.7226)
Hansen J-test	0.884	-	0.896	-
AR(1)	0.000	-	0.033	-
AR(2)	0.302	-	0.397	-

Notes: 1. *p<0.1, **p<0.05, ***p<0.001.
2. Countries are categorized by income level based on World Bank.

Next, looking at the variables of consumption-based emissions and GDP per capita, the dependent variable has a positive relationship like the production-based emission model. However, the square variable of GDP per capita has insignificant result. This means that as the economy grows, CO_2 emissions will continuosly increase. In other words, the graph form of inverted U-shape does not appear and the EKC hypothesis is not established in the consumption-based emission model. This means that consumption-based emissions continue to rise for upper-middle income countries. In other words, as the economies of upper-middle income countries become more advanced, carbon-intensive industries move overseas due to environmental regulations. Essentially, carbon leakage is occurring, and previous studies have pointed out similar problems (Qin et al., 2021; Yu, Cai and Sun, 2021).

The industry and energy imports variables have positive influence on consumption-based emissions. Unlike the production-based model, the trade openness variable showed a positive coefficient value, although it was not statistically significant in system-GMM estimation. The upper-middle income countries tend to import nonenvironmental goods (i.e., carbon-intensive goods or raw materials) from developing countries (pollution shelter hypothesis). Therefore, the effect of international trade on CO_2 emissions depends on a country's level of development (Antweiler, Copeland and Taylor, 2001; Frankel and Rose, 2005; Le, Chang and Park, 2016). Therefore, it is considered that the coefficient value came out negative in the production-based model, whereas the negative result was obtained in the consumption-based model. Unlike the production-based model, the coefficient of the FDI variable in the system-GMM estimation was negative, and statistically insignificant results were found in the FGLS estimation.

Table 5. Estimation Results for the Lower-middle Income Countries

Variable	$lnCO_2$		$lnCO_2con$	
	Sys-GMM	**FGLS**	**Sys-GMM**	**FGLS**
L1	0.9440*** (0.0297)	-	0.8540*** (0.0185)	-
lnGDP	0.3288** (0.1443)	1.3021** (0.5572)	0.9688*** (0.2085)	−1.0360 (0.7674)
$lnGDP^2$	−0.0119 (0.0088)	−0.0519 (0.0373)	−0.0567*** (0.0142)	0.1219** (0.0532)
Industry	−0.0026 (0.0016)	0.0038* (0.0022)	0.0023* (0.0014)	0.0071** (0.0029)
Trade openness	0.0013** (0.0005)	0.0004 (0.0004)	−0.00008 (0.0005)	0.0005 (0.0007)
FDI	−0.0009** (0.0004)	−0.0007 (0.0003)	−0.0002 (0.0006)	0.0032 (0.0021)
Energy imports	0.0004** (0.0002)	0.0008** (0.0003)	0.0012*** (0.0001)	0.0022*** (0.0004)
lnEnergycon	0.0140** (0.0126)	0.5663*** (0.0347)	−0.0170 (0.0119)	0.1981*** (0.0328)
Constants	−1.8070** (0.6183)	−7.8663*** (2.0690)	−4.0659*** (0.7720)	0.3887 (2.7535)
Hansen J-test	0.984	-	0.987	-
AR(1)	0.000	-	0.000	-
AR(2)	0.342	-	0.104	-

Notes: 1. *p<0.1, **p<0.05, ***p<0.001.
2. Countries are categorized by income level based on World Bank.

Table 5 shows the estimation results for lower-middle income countries. First, the production-based emissions and the variable of GDP per capita have a positive relationship, and the square term variable of GDP per capita was not statiscally significant result in the lower-middle income countries. In other words, the inverted U-shaped EKC hypothesis was not established, and CO_2 did not decrease at some point while gdp increased. This result is consistent with the results of most previous studies.

Industry variable was not statistically significant in system-GMM estimation, but has positive impact on the production-based emissions in FGLS. Unlike upper-middle income countries, trade openness has a positive effect on production-based emissions in lower-middle income countries. As explained above, while upper-middle income countries can easily import advanced technologies and environmentally friendly technologies through trade, lower-income countries prioritize economic growth and thus import relatively less environmentally friendly technologies through trade. Tamazian and Rao (2010) also pointed out the problem and suggested that it can be weakened by institutional quality.

Meanwhile, the coefficient value of the FDI variable was negative. Contrary to what is mentioned in Table 4, as the investment of multinational companies in lower-middle income countries increases, multinational companies bring more eco-friendly products. Consequently, FDI can reduce production-based emissions. The energy imports variable and the per capita energy consumption variable also had positive influences on the production-based emissions even in the lower-middle income countries.

Next, looking at the variables of consumption-based emissions and GDP per capita, the dependent variable has a positive relationship, and the square variable of GDP per capita has a negative relationship. On the other hand, in the FGLS estimation, GDP per capita was not statistically significant, and the the square of GDP term has a positive impact on the consumption-based emissions.

Industry variable has a positive impact on the consumption-based emissions. Both trade openness and FDI variables were not statistically significant. On the one hand, the energy imports variable and the per capita energy consumption variable which was not statistically significant had positive effects on the consumption-based emissions as in the production-based model.

In the end, Hansen J-test and first, second-order autocorrelation tests were used to examine the instrument quality in all models. Hansen J-test was performed to test based on level and difference equations and over the identification restriction validity, respectively. As the null hypothesis cannot be rejected, the instrumental variable used can be said to be appropriate. In other words, there are no problems with the validity of lagged instruments used. The Arellano–Bond test confirms the autocorrelation hypothesis in first-order AR (1), while the second-order AR (2) autocorrelation cannot be rejected in all models. Therefore, the instrumental variable with only one time-lag used in this model was appropriate. In conclusion, the system GMM estimation results indicate that the estimation results are robust.

5. Conclusion and Policy Implications

This study analyzed the difference between production- and consumption-based CO_2 emissions according to economic growth in ninety-three countries categorized by income level from 1995 to 2014 by using system GMM. There are many studies on economic growth and CO_2 emissions, and research on the relationship between consumption-based emissions and economic growth have recently been conducted. We studied the difference between the production- and the consumption-based model by dividing it into two groups in ninety-three countries. Moreover, our study examined the EKC hypothesis by setting control variables that affect consumption-based CO_2 emissions and adding the square terms of economic growth variables.

In the upper-middle income countries, according to the production-based regression analysis results, the EKC hypothesis was satisfied, and the EKC hypothesis was established as the coefficient value of the GDP per capita variable was positive and the square term was negative. Additionally, the trade openness variable had a negative sign, and all other control variables had positive results. On the other hand, looking at the results in the consumption-based model, a positive sign with the coefficient value of the GDP per capita variable, and the square term was insignificant, and the EKC hypothesis was not established. Moreover, unlike the production-based model, the FDI variable had a negative sign, and all other control variables showed positive results.

In the lower-middle income countries, according to the production-based regression analysis results, the EKC hypothesis dissatisfies the inverted U-shape, and the EKC hypothesis was not established as the coefficient value of the GDP per capita variable was positive and the square term was insignificant. In addition, the FDI variable had a negative sign, and all other control variables had positive results except the industry variable. On the contrary, in system GMM estimation, looking at the results in the consumption-based model, GDP per capita, the dependent variable has a positive relationship, and the square variable of GDP per capita has a negative relationship. Meanwhile, in the FGLS estimation, GDP per capita was not statistically significant, and the square of GDP term has a positive impact on the consumption-based emissions. The industry and energy imports variables had a positive sign, and all other control variables were insignificant.

Industry, energy imports, and per capita energy consumption variables both had positive impacts on the production- and consumption-based CO_2 emissions in most groups. These elements can be seen as essential to ultimately reduce CO_2 emissions. In the end, breaking away from the manufacturing-oriented industrial structure and reducing energy consumption and energy imports are a way to reduce both production- and consumption-based CO_2 emissions. These were suggested that previous studies (Al-Mulali et al., 2015; Shahbaz et al., 2013).

This study suggests that environmental activists, decision-makers, and others should consider all environmental policies, such as the 2015 Paris Agreement and carbon neutrality policy, not only production-based options but also consumption-based options. Commodities produced in other countries are somewhat responsible to the country that imports them, and the emission measurement standard considering this should be considered.

Nevertheless, this study needs to be supplemented. First, more research and sophisticated estimation are needed in consumption-based models of lower-middle income countries. Second, as the CO_2 emission factors studied in previous studies were studied by sector, such detailed studies need to be conducted in the consumption-based CO_2 model. This will be supplemented in future research.

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