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Does Economic Growth Impact Environmental Degradation? Evidence from OECD Countries Using the Panel Dynamic Threshold Model

Araştırma Makalesi /Research Article

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ABSTRACT: *Various studies and research were carried out, particularly by developed countries, to ensure that the production process, a fundamental part of economic growth and development, is carried out in an environmentally sustainable manner. In this context, the theory known as the Environmental Kuznets Hypothesis (EKH), which addresses the association between income levels and environmental damage, has been widely tested by researchers. This study investigates the relationship between income levels and environmental damage in OECD member countries and tests the validity of the EKH. For this purpose, data covering the period 1965-2020 were analyzed using a panel data-based dynamic threshold model. The analysis results suggest that the income threshold value is calculated as 3,204. The findings confirm the validity of the EKH. Additionally, the results reveal that economic growth negatively impacts the environment and leads to environmental degradation until the income threshold level is reached. However, in line with the hypothesis, once the income threshold level is exceeded, the adverse effects of economic growth on environmental degradation gradually diminish. When all findings are considered together, it is clearly demonstrated that the association between income level and environmental damage exhibits an inverted U-shape pattern.*

Keywords: *Economic Growth, Environmental Damage, Environmental Kuznets Hypothesis, Income Level, Panel Dynamic Threshold Model.*

Ekonomik Büyüme Çevresel Tahribata Etki Eder Mi: OECD Ülkelerinden Panel Dinamik Eşik Modeli İle Kanıtlar

ÖZ: *Ülkelerin ekonomik büyüme ve kalkınmasında önemli bir yer tutan üretim sürecinin çevreye duyarlı olarak yürütülmesi için özellikle gelişmiş ülkelerin başını çektiği ülkelerce çeşitli çalışmalar ve araştırmalar yürütülmektedir. Bu bağlamda literatürde Çevresel Kuznets Hipotezi olarak adlandırılan gelir düzeyiyle çevresel tahribatlar arasındaki ilişkileri araştıran teori günümüzde birçok araştırmacı tarafından da sınanmaktadır. Bu çalışmanın amacı da, OECD üyesi ülkelerde gelir düzeyleri ile çevresel tahribatlar arasındaki ilişkilerin araştırılmasıyla Çevresel Kuznets Hipotezi'nin varlığının sınanmasıdır. Bu amaçla 1965-2020 dönemine ait veriler panel veri analizine dayalı dinamik eşik model kullanılarak incelenmektedir. Analiz sonucunda gelir eşik değeri 3.204 olarak hesaplanmıştır. Analiz bulguları Çevresel Kuznets Hipotezi'nin geçerli olduğunu ortaya koymaktadır. Bununla birlikte ekonomik büyümenin gelir eşik düzeyine ulaşıncaya kadar çevreye olumsuz etkilerde bulunduğunu ve çevreyi tahrip ettiğini ortaya koymaktadır. Ancak hipoteze uygun olacak şekilde gelir eşik gelir düzeyinin aşılmasından sonra ekonomik büyümenin çevresel tahribatlar üzerindeki olumsuz etkisinin giderek azaldığını da ortaya koymuştur. Tüm sonuçlar birlikte değerlendirildiğinde gelir düzeyi ile çevresel ilişkilerin ters-U şeklinde olduğu net bir şekilde ortaya konulmuştur.*

Anahtar Kelimeler: *Ekonomik Büyüme, Çevresel Tahribat, Çevresel Kuznets Hipotezi, Gelir Düzeyi, Panel Dinamik Eşik Modeli.*

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1. Introduction

Throughout history, economic growth and progress have been fundamental objectives for all nations. However, these processes have also brought about numerous challenges. In particular, many of today's developed countries, driven by the motto of "*growth at any cost*", have contributed to severe and irreversible environmental issues; first within their own borders and also on a global scale. The industrialization process, in particular, has played a remarkable role in economic growth and development while simultaneously exacerbating environmental degradation. Whether developed, developing, or underdeveloped, all nations have pursued increased welfare, often at the expense of the planet. This trajectory has led to what the United Nations refers to as "*growth without a future*". This model is characterized by the disregard for environmental sustainability and the reckless destruction of natural resources in the pursuit of economic expansion. As a result, the world has been pushed toward an environmental crisis.

Economic growth and development have historically been carried out with little regard for environmental consequences. However, a growing awareness of environmental issues has led to the emergence of concepts such as environmentally conscious sustainable growth and green growth, driven by the understanding that "*there is no planet B*". This paradigm shift has fostered the recognition that sustainable growth and development can only be achieved through a sustainable environmental consciousness. Consequently, countries worldwide have started implementing economic policies aiming to adopt this new perspective. In this context, alternative approaches to the energy factor, one of the most critical inputs in production, which is a key determinant of economic growth and development, have been investigated, leading to the formulation of new energy policies. The most significant step in this process has been the transition from carbon-intensive fossil fuels to sustainable and renewable energy sources. Moreover, even in cases where carbon-based fossil fuels continue to be used, a more cautious and responsible consumption approach has been adopted, prioritizing processes that minimize environmental damage.

The EKH hypothesis, which establishes a link between income levels and environmental degradation, emerged as a key theoretical framework in the literature. It suggests that carbon emissions, one of the most critical indicators of environmental pollution and degradation, initially increase with rising income levels. However, once income exceeds a certain threshold, emissions begin to decline, suggesting an inverted U-shaped relationship between economic growth and environmental impact. In line with this theoretical perspective, the present study investigates the validity of the EKH for 28 OECD countries for the period 1965-2020 using the panel dynamic threshold model. This study consists of five sections. Following the Introduction, the second section provides a theoretical background and a literature review. The third section presents the dataset, methodological framework, and econometric model employed in the analysis. The fourth section addresses the empirical results, while the fifth and final section offers a general evaluation and conclusion. The main idea behind selecting the OECD countries in this study is to show the extent of environmental sensitivity in a group of mostly developed countries. Although there are many studies in the literature with this idea in mind, there are relatively few studies that investigate this issue within the OECD context using threshold analysis. This situation is important because of the possible contribution of this study to literature.

2. Theoretical Framework and Literature Review

The EKH emerged during a period when the global economic growth and development process was in its most challenging phase, marked by significant environmental degradation. This was particularly evident in the context of concepts such as "*growth at any cost*" and "*unsustainable growth*". The theory is fundamentally an extension of the Kuznets Curve, originally developed by Simon Kuznets, which describes an inverted U-shaped relationship between economic growth and income inequality. EKH applies this framework to income levels and environmental pollution. It suggests that environmental degradation initially intensifies as income levels increase. However, once income reaches a certain threshold, environmental degradation and pollution begin to decline (Apergis and Payne, 2010: 650).

The EKH has primarily been used to highlight and analyze the negative externalities associated with the economic activities of industrialized or industrializing nations. In the initial stages of economic growth, particularly in developing countries, the emphasis on rapid industrialization often leads to increased environmental degradation due to the reliance on pollution-intensive technologies and production processes. This forms the core premise of the hypothesis. However, as economic growth continues, the resulting wealth accumulation gradually shifts national priorities. Increased investments in research and development foster the adoption of cleaner production technologies, reducing reliance on environmentally harmful practices. Moreover, as economic growth progresses, heightened environmental awareness promotes a shift toward sustainable development. This transition is further reinforced as industrial sectors, initially dominant in the economy, give way to service-based and knowledge-intensive industries. Consequently, environmental challenges are mitigated, and sustainable energy utilization is promoted alongside economic expansion and environmental improvement. In this process, the initial rise in environmental pollution due to low income levels is followed by a turning point at which increased income fosters developmental improvements, environmental consciousness strengthens, and environmental degradation decreases, ultimately forming a parabolic relationship (Örnek and Türkmen, 2019: 111-112).

In the literature, many studies investigated the EKH. The earliest empirical studies in this domain were pioneered by Grossman and Krueger (1991, 1995), followed by Shafik and Bandyopadhyay (1992), Selden and Daging (1995), Ekins (1997), Panayotou (1997), Roberts and Grimes (1997), Stern et al. (1996), Shafik (1994), and Vincent (1997). These studies provided empirical validation for the EKH hypothesis. Additionally, numerous studies examined EKH dynamics in multi-country settings, making significant contributions to the literature. Notable examples testing the validity of the EKH hypothesis include studies carried out by Grossman and Krueger (1991, 1995), Selden and Song (1994), Tucker (1995), Komen et al. (1997), Dijkgraaf and Vollebergh (2001), Heil and Selden (2001), Stern and Common (2001), Perman and Stern (2003), Dinda (2004), Galeotti et al. (2006, 2009), Apergis and Payne (2010), Pao and Tsai (2010), Jaunky (2011), Arouri et al. (2012), Farhani and Rejeb (2012), Cho et al. (2014), Beck and Joshi (2015), Georgiev and Mihaylov (2015), Heidari et al. (2015), Bilgili et al. (2016), Jebli et al. (2016), Acar et al. (2018), Balsalobre-Lorente et al. (2018), Cheng et al. (2019), Danish et al. (2019), Özkan et al. (2019), Sohag et al. (2019), Amin et al. (2020), Nawaz et al. (2021), Aminata et al. (2022), Awan et al. (2022), Htieke (2022), Bao and Lu (2023), Phiri et al. (2023), and Wang et al. (2023).

Moreover, there also are studies focusing on single-country analyses of the EKH hypothesis, including those carried out by Shabani and Shahnazi (2019), Shahbaz et al. (2020), Egli (2001), Kharbach and Chfadi (2017), Jalil and Mahmud (2009), Fosten et al. (2012), Lau et al. (2014), Balaguer and Cantavella (2016), Alshehry and Belloumi (2017), Danish et al. (2018), Dong et al. (2018), Zambrano-Monserrate et al. (2018), Mikayilov et al. (2018), Chen et al. (2022), Sinha and Shahbaz (2018), Friedly and Getzner (2003), and Guo et al. (2022). These studies further examined the applicability of the EKH hypothesis in specific national contexts.

Finally, the prevalence of studies based on the panel threshold model, which serves as the fundamental empirical framework of this study, is significant. In this context, Ouyang et al. (2019) tested the EKH hypothesis using a panel dynamic threshold model in their study on 30 OECD countries for the period 1998-2015. The results estimated the income threshold value at 1.273 and demonstrated that income had a positive impact on air pollution up to this threshold, whereas it exerted a negative effect once the threshold was surpassed. These results confirm the EKH hypothesis' validity in the examined OECD countries.

Similarly, in a study carried out by Chen et al. (2022) covering 95 countries, including developing, developed, and highly developed nations, the association between renewable energy consumption and income was examined employing data from the period 1995-2015. The analysis, which estimated a threshold value of 1.475, revealed that under short- and long-term assumptions, the short-term threshold value was negative and statistically significant (-0.255) for developing countries, whereas it was positive and significant for all other country groups. Considering all results collectively, they indicate that an increase in renewable energy consumption has a negative and significant effect on carbon emissions, particularly in highly developed and developed countries. In contrast, Akbulut (2022) examined the association between income and carbon emissions in BRICS countries for the period 1995-2015 and found no significant relationship, concluding that the EKH hypothesis was not valid in these economies.

Çatık et al. (2023) examined the association between carbon emissions from the transportation sector and income within the framework of the EKH for 28 OECD countries for the period 1990-2019. The panel dynamic threshold analysis results estimated the threshold value at 10.062 and confirmed that the relationship between the variables aligned with the EKH hypothesis. Likewise, Uche et al. (2023) examined the validity of the EKH in the Indian economy for the period 1980-2018, demonstrating that income had significant long-term effects on environmental pollution and confirming the EKH hypothesis' validity. Similarly, a study carried out by Acaroğlu et al. (2023) analyzing the EKH hypothesis' validity in the Turkish economy for the period 1971-2015 estimated an income threshold of $11,006, providing further evidence in support of the EKH hypothesis.

3. Dataset, Methodology, and Econometric Model

This study examines whether the Environmental Kuznets Hypothesis (EKH) is valid for 28 OECD member countries[3] for the 1965-2020 period using the panel dynamic threshold model. In other words, this study investigates whether there is a threshold effect in the association between income (or economic growth) and the environment. If such an effect is identified, the nature of the relationships among the relevant variables will be analyzed. The primary rationale for focusing on this group of countries is the rapid upward trend in income and economic growth processes, which has been accompanied by significant levels of environmental degradation. The main reason for selecting the specified time frame is the availability of data required for the analyses. For this purpose, carbon emissions (*carbon*) were used as a proxy for environmental effects, with their logarithmic values considered. The economic growth (*growth*) variable was represented by the logarithm of per capita income. In addition to these key variables, certain control variables that could influence carbon emissions and contribute to obtaining robust results in the analyses were incorporated into the estimation process. The first control variable is urbanization, represented by the logarithmic values of the urban population level (*urbanization*). The second control variable is *energy consumption*, which is also included in the logarithmic form. All the data were obtained from the World Bank's official website.

This study employs the dynamic threshold model, which extends the static model for endogenous estimators proposed by Hansen (1999), as expanded by Kremer et

[3] Although they are OECD member countries, Czechia, Slovakia, Estonia, Slovenia, Costa Rica, Lithuania, Latvia, Israel, Poland, and Hungary were excluded from the scope due to a lack of accessible data.

al. (2013). The dynamic threshold model builds upon the cross-sectional threshold model developed by Caner and Hansen (2004), incorporating Generalized Method of Moments (GMM)-type estimators that allow for the use of endogenous variables. This model is represented by Equation (1):

$$y_{it} = \mu_{it} + \beta_1' z_{it} I(q_{it} \leq \gamma) + \beta_2' z_{it} I(q_{it} > \gamma) + \varepsilon_{it} \quad (1)$$

In regression model (1), y_{it} represents the dependent variable and the fixed effect, while $\varepsilon_{it} \approx (0, \sigma^2)$ denotes the independently and identically distributed error term. The function *I(.)* serves as an indicator function representing the regime in the model, whereas q_{it} is employed as the threshold variable and ϒ as the threshold value. Additionally, z_{it} in the model constitutes an m-dimensional vector of explanatory variables, including the lagged value of the dependent variable and other endogenous variables. The explanatory variable vector is further divided into two subsets in the model: z_{1it}, which consists of explanatory variables correlated with e_{it}, and z_{2it}, which comprises endogenous variables independent of e_{it} (Akıncı et al., 2018: 199; Sevinç et al., 2022: 358; Kremer et al., 2013: 4).

The next step after estimating the model presented in Eq. 1 is to determine the growth threshold value using the Two-Stage Least Squares (2SLS) method. Following the study carried out by Caner and Hansen (2004), the reduced-form regression for the endogenous variables z_{2it}, which are functions of the instrumental variables X_{it}, is first estimated. Subsequently, in the structural equation, the estimated values of the endogenous variables $\hat{z}_{2it}$ obtained from the model replace the endogenous variables z_{2it}. The model in Eq. 1 is then estimated utilizing the Ordinary Least Squares (OLS) technique for a given fixed threshold value ϒ. This process is repeated for subsets of q. Among the obtained threshold values, the one with the lowest sum of squared error terms $S(\gamma)$ is selected as the appropriate threshold value $\hat{\gamma}$, as expressed in Eq. 2 (Hansen, 2000: 578; Akıncı et al., 2018: 200; Akıncı and Şahin, 2022; 1495):

$$\hat{\gamma} = argmin\, S_n(\gamma) \quad (2)$$

Considering the studies carried out by Hansen (1999), Akıncı et al. (2018), Kremer et al. (2013), and Caner and Hansen (2004), the critical values for the *growth* threshold variable (CI: 95%) are calculated. The constraint equation required for calculating the critical values is given as:

$$\Gamma = \{\gamma : LR(\gamma) \leq C(\alpha)\} \quad (3)$$

In Eq. 3, $LR(\gamma)$ represents the asymptotic distribution of the likelihood ratio statistic, while $C(\alpha)$ denotes the 95% quantile of this distribution. After determining the appropriate threshold value $\hat{\gamma}$, the slope coefficients in the dynamic threshold model are estimated making use of the GMM based on the previously identified instrumental variables and the estimated threshold value.

The effect of the *growth* threshold value on carbon emissions can then be analyzed using the dynamic threshold model specified in Eq. 4:

$$Carbon_{it} = \mu_{it} + \beta_1 Growth_{it} I(Growth_{it} \leq \gamma) + \delta_1 I(Growth_{it} \leq \gamma) + \beta_2 Growth_{it} I(Growth_{it} > \gamma) + \psi z_{it} + \varepsilon_{it} \quad (4)$$

In Eq. 4, the variable $Growth_{it}$ represents the *growth* threshold effects for the two regime types, while z_{it} denotes the vector of control variables. The coefficients β_1 and β_2 represent the regime slope coefficients, and δ_1 denotes the regime intercept coefficient.

As stated by Roodman (2009), using all lagged values of the dependent variable as instrumental variables in the regime regression analysis ensures that the coefficient estimates are both unbiased and consistent. Therefore, following the studies carried out by Arellano and Bover (1995), all lagged values of the dependent variable were incorporated into the model as instrumental variables.

4. Empirical Results

Determining whether the variables employed in the models are stationary and, if so, at what level stationarity occurs is an important aspect of the analysis. When employing a panel dataset to examine for the presence of unit roots, assessing cross-sectional dependence is also a significant consideration. In general terms, the choice of cross-sectional dependence test depends on the relationship between the time dimension and the cross-sectional dimension. Specifically, the Breusch-Pagan (1980) CD LM1 test is applied when the time dimension exceeds the cross-sectional dimension (T > N). If T = N, then the Pesaran (2004) CD LM2 test is employed. The Pesaran (2004) CD LM test is employed if T < N (Göçer, 2013: 5092). In this study, since the dataset consists of 28 countries (N = 28) and spans 56 years (T = 56), where T > N, the Breusch-Pagan CD LM1 test was utilized to detect cross-sectional dependence. The Breusch-Pagan CD LM1 test is computed using the following equation:

$$LM = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij} \hat{\rho}_{ij}^2 \rightarrow \chi^2 \frac{N(N-1)}{2} \quad (5)$$

where $\hat{\rho}_{ij}$ represents the correlation coefficients derived from the model residuals. The asymptotic χ^2 distributions are obtained for a constant range of N as $T_{ij} \rightarrow \infty$ for all i and j, under the assumption of normally distributed errors. In this context, the null hypothesis posits no cross-sectional dependence, whereas the alternative hypothesis suggests the presence of correlation between cross-sectional units (cross-sectional dependence exists). If cross-sectional dependence is rejected in a panel dataset, first-generation unit root tests are deemed more appropriate. Conversely, if cross-sectional dependence is confirmed, employing second-generation unit root tests yields more reliable results (Çınar, 2010). Table 1 presents the results of the Breusch-Pagan CD LM1 test, which is used to assess cross-sectional dependence. Table 1 indicates the presence of a correlation between cross-sectional units. Accordingly, it can be concluded that cross-sectional dependence is present, and second-generation unit root tests should be used to detect the presence of unit roots.

Table 1: Breusch-Pagan CD-LM1 Cross-Sectional Analysis Results

Variables	Test Statistic	Probability
*Ln*Carbon	10534.11***	0.000
LnIncome (Growth)	20360.09***	0.000
*Ln*Urbanization	18452.91***	0.000
*Ln*Energy Consumption	13489.33***	0.000
Entire Equation	4519.614***	0.000

Note: The *** symbol indicates that the coefficient for the respective variable is statistically significant at the 1% significance level, thereby confirming the presence of cross-sectional dependence.

The correlation relationships between the cross-sectional units of the variables highlight the necessity of employing second-generation unit root tests to reveal the stationarity levels of the variables. In this context, Table 2 presents the CADF and CIPS unit root test results for panel data variables. While the CADF test conducts a unit root test for each cross-sectional unit in the panel, the CIPS test applies a common unit root test to the entire panel as a whole. The CADF test is applicable in cases where T > N or N > T. If the calculated CADF test statistic is higher in absolute value than the CADF critical values, the null hypothesis indicating non-stationarity is rejected in favor of the alternative hypothesis. It suggests that the series is stationary (Pesaran, 2007: 265-312). The CADF test statistic is computed using the following equations:

$$y_{it} = (1-\varphi_i)\mu_i + \varphi_i y_{i,t-1} + u_{it} \ , i = 1,\dots,N; t = 1,\dots,T \tag{6}$$

$$u_{it} = \gamma_i f_t + \varepsilon_{it} \tag{7}$$

where f_t represents unobserved common effects, and ε_{it} denotes the individual-specific error term. The combination of Eq. 6 and Eq. 7 yields:

$$\Delta y_{it} = \alpha_i + \beta_i y_{i,t-1} + \gamma_i f_t + \varepsilon_{it} \tag{8}$$

where $\alpha_i = (1-\varphi_i)\mu_i$, $\beta_i = -(1-\varphi_i)$ and $\Delta y_{it} = y_{it} - y_{i,t-1}$. In this context, the null and alternative hypotheses for the CADF analysis are formulated as follows (Pesaran, 2007: 268):

$$H_0: \beta_i = 0 \text{ For all i's(Series is not stationary)}$$
$$H_1: \beta_i < 0 , i = 1,2,\dots,N_1 , \beta_i = 0 , i = N_1+1, N_1+2,\dots,N \text{ (Series is stationary)} \tag{9}$$

On the other hand, the CIPS test is conducted by averaging the stationarity statistics calculated for each cross-sectional unit, providing stationarity insights for the panel as a whole. Similar to the CADF test, if the calculated CIPS test statistic is higher in absolute value than the CIPS critical values, the null hypothesis of non-stationarity is rejected in favor of the alternative hypothesis; which suggests that the series is stationary. In general, the CIPS test statistic is calculated as follows:

$$CIPS = N^{-1}\sum_{i=1}^{N} CADF_i \quad (10)$$

Table 2: CADF and CIPS Unit Root Test Results

CADF Unit Root Test Results								
Countries	***LnCarbon***		***LnIncome (Growth)***		***LnUrbanization***		***LnEnergy Consumption***	
	p	**t-Stat**	**p**	**t-Stat**	**p**	**t-Stat**	**p**	**t-Stat**
Austria	0	-2.938	0	-2.350	4	0.344	0	-3.442*
Australia	0	-4.438**	0	-2.222	0	0.334	0	-4.706***
Belgium	0	-2.780	0	-2.707	1	-2.183	1	-3.193
Canada	0	-2.737	0	-2.189	7	-1.834	0	-2.597
Chile	1	-3.587*	0	-1.924	2	-0.800	1	-3.300
Colombia	0	-2.703	0	-1.593	2	-1.780	0	-1.900
Denmark	0	-3.541*	1	-3.455*	5	-2.625	0	-4.038**
France	0	-0.595	0	-4.733***	4	-3.042	0	-4.181**
Finland	0	-4.379**	1	-3.607*	6	-2.164	0	-2.410
Germany	2	-4.152**	0	-2.645	1	-2.119	5	-5.932***
Greece	0	-2.793	0	-1.162	2	-1.745	2	-5.637***
Iceland	0	-3.510*	1	-4.358**	3	-3.906**	0	-1.176
Ireland	5	-2.637	0	-2.454	2	-2.603	5	-2.166
Italy	0	-3.302	0	-1.674	1	-1.736	0	-3.037
Japan	0	-3.532*	0	-0.978	1	-3.273	0	-2.536
South Korea	0	-0.896	0	-2.564	5	-3.996**	0	-0.304
Luxembourg	0	-1.474	0	-3.357	3	-2.706	0	-1.550
Mexico	0	-2.443	0	-4.098**	1	-1.400	0	-2.158
Holland	7	-4.435**	0	-2.472	3	-2.400	0	-1.639
New Zealand	0	-3.777*	0	-3.696*	1	-1.865	0	-3.502
Norway	1	-4.173**	0	-1.300	6	-3.658*	0	-3.857**
Portugal	0	-2.156	0	-1.588	3	-3.757*	0	-3.045
Spain	0	-3.541*	0	-3.098	1	-4.798***	0	-2.571
Sweeden	0	-2.015	0	-3.269	6	-1.341	0	-2.058
Switzerland	0	-4.470**	0	-3.806**	2	-2.149	0	-4.344**
Türkiye	0	-2.540	0	-2.262	2	-2.672	0	-2.554
England	0	-2.581	1	-2.832	1	-2.755	0	-4.538***
USA	0	-4.309**	0	-1.765	1	-2.700	0	-2.926
Critical Values	1%	-4.49	1%	-4.49	1%	-4.49	1%	-4.49
	5%	-3.79	5%	-3.79	5%	-3.79	5%	-3.79
	10%	-3.44	10%	-3.44	10%	-3.44	10%	-3.44
CIPS Unit Root Test Results								
Panel	0	-3.087***	0	-2.648*	0	-2.631*	0	-3.066***
Critical Values	%1	-2.79	%1	-2.79	%1	-2.79	%1	-2.79
	%5	-2.66	%5	-2.66	%5	-2.66	%5	-2.66
	%10	-2.59	%10	-2.59	%10	-2.59	%10	-2.59

Note: p denotes the optimal lag lengths. The p-value was computed using a Monte Carlo simulation with 10,000 iterations. The selection of optimal lag lengths was based on the Schwarz Information Criterion, and analyses were conducted with a maximum lag length of eight. The analyses employed both a constant and a trend structure, and the Bai and Ng method was used for factor selection. The Schwert method was applied in determining the maximum number of factors. *, **, and *** indicate that the corresponding coefficient is stationary at the 10%, 5%, and 1% significance levels, respectively.

The results of the CADF test, which presents the stationarity information of individual countries in Table 2, emphasize that the *Carbon* variable is stationary at level [*I(0)*] for Australia, Japan, Finland, Denmark, Iceland, Germany, the

Netherlands, New Zealand, Norway, Chile, Switzerland, Spain, and the USA. Similarly, the *Growth* variable is found to be stationary at level [*I(0)*] for Denmark, France, Finland, Iceland, Mexico, New Zealand, and Switzerland. The Urbanization variable is level-stationary [*I(0)*] in Iceland, South Korea, Norway, Portugal, and Spain. However, the *Energy Consumption* variable is stationary at level [*I(0)*] for Austria, Australia, Denmark, France, Germany, Greece, Norway, Switzerland, and England. However, the results of the CIPS test, which assesses the stationarity properties of the entire panel, reveal that all variables considered in the model are stationary at level [*I(0)*]. Overall, it can be stated that the variables used in the analyses are integrated at level.

Variables being stationary at level across the countries in the panel set highlight that the coefficients representing the relationships between these variables can be directly estimated. In this context, Table 3 presents the dynamic panel threshold model analysis results, which reflect the effect of the income threshold on the relationship between environmental degradation and economic growth.

Table 3: Dynamic Panel Threshold Model Results

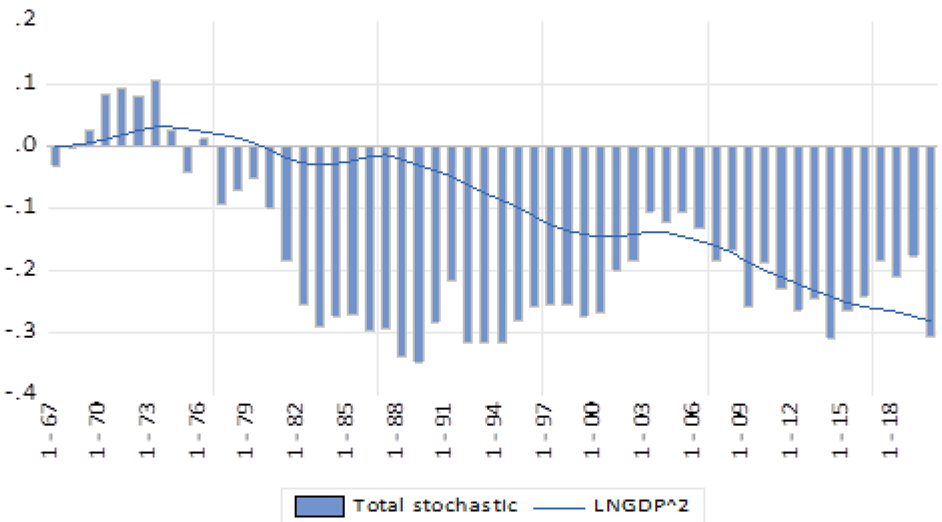
Dependent Variable: *LnCarbon*	
Threshold Value and Confidence Intervals for *LnIncome (Growth)*	
Threshold Value (γ)	3.204%**
95% Confidence Intervals	[2.070, 4.999]
Regime-Dependent Regressors:	
Effect of the *LnIncome (Growth)* Variable	
Low Regime (β_1)	1.497** (0.048)
High Regime (β_2)	-1.959* (0.075)
Regime-Independent Regressors: Effect of Control Variables	
Sabit (δ)	18.601*** (0.000)
LnUrbanization	1.173* (0.057)
LnEnergy Consumption	1.862** (0.041)
LnEnergy Consumption LnUrbanization*	3.248*** (0.000)
Model Statistics	
R^2	0.765
F (Probability)	22.259*** (0.000)
DW	1.823
Unit Effect:	Yes
Time Effect:	Yes
Number of Observations	1568
Instrumental Variables	
$LnCarbon_{t-1}$, $LnCarbon_{t-2}$, $LnCarbon_{t-3}$	

Note: *, **, and *** denote significance at 10%, 5%, and 1%. Ln represents the natural logarithm of the corresponding variable. The values in parentheses indicate the p-values associated with each coefficient. Instrumental variables were selected based on the maximum 10-lag length using the Schwarz Information Criterion (SIC).

Table 3 indicates that the estimated growth threshold value is 3.204%, and this threshold falls within the 95% confidence interval. The analysis results reveal that, until the 3.204% growth threshold is reached, a 1% rise in economic growth causes a 1.497% increase in carbon emissions. This finding emphasizes that growth exacerbates environmental degradation up to this point. However, after surpassing the 3.204% growth threshold, a 1% rise in economic growth results in a 1.959% decline in carbon emissions, indicating that growth beyond this threshold reduces environmental degradation. Accordingly, within the OECD country group, the association between economic growth and environmental impact aligns with the EKH. This suggests a parabolic pattern, confirming the presence of an inverse-U-shaped relationship between the variables. This finding is further validated by Figure 1. Beyond this primary conclusion, the results also show that urban population growth directly affects the environment. A 1% rise in the urban population ratio leads to a 1.173% rise in carbon emissions, emphasizing that urbanization accelerates environmental degradation. A similar pattern is observed for energy consumption; a 1% rise in energy consumption causes a 1.862% increase in carbon emissions, indicating that energy consumption significantly contributes to environmental degradation. Additionally, the combined effect of rapid urbanization and increasing energy consumption intensifies the impact. A 1% rise in energy consumption accompanying urbanization results in a 3.248% rise in carbon emissions, illustrating the amplifying effect of urban energy use on environmental damage.

Finally, it is important to note that the relatively high explanatory power of the model, its overall statistical significance, and the absence of autocorrelation issues confirm the robustness and reliability of the results.

Figure 1: Relationships between Growth and the Environment



5. Conclusion

This study examines the validity of the EKH in 28 OECD member countries for the period 1965-2020 using a panel dynamic threshold model. In other words, this study investigates whether an economic growth threshold influences the association between income (or economic growth) and the environment, and if such an effect is determined, it explores the nature of the relationships among the relevant variables.

For this purpose, this study first examines cross-sectional dependence among the variables, employing the Breusch-Pagan CD LM1 test. The results indicate cross-sectional dependence at the individual variable level and across the entire panel. Consequently, second-generation unit root tests are required to determine the stationarity properties of the variables. Accordingly, CADF and CIPS unit root tests were conducted, revealing that all variables considered within the model are stationary at their level [*I(0)*]. Following the identification of the stationarity of the variables, a dynamic panel threshold model is employed to estimate the impact of the income threshold on the relationship between economic growth and environmental quality. The analysis results revealed that economic growth increases carbon emissions until the threshold growth rate of 3.204% is reached. However, once this threshold is surpassed, further increases in the growth rate lead to a reduction in environmental degradation. This finding confirms the validity of the EKH and highlights the significant role of the income threshold in the growth-environment relationship. Besides, these results underscore that urban population growth accelerates environmental degradation. Similarly, rising energy consumption produces comparable adverse effects. The results show that growth needs to be conducted in an environmentally sensitive approach in OECD countries. However, the fact that population significantly increases environmental damage also reveals the necessity of giving importance to population management or population projections in OECD countries. The results also emphasize that the increasing energy demand should be provided from renewable energy sources rather than carbon emission-based energy sources that will increase environmental damage.

When considered holistically, the results emphasize the necessity of establishing sustainable and forward-looking growth conditions within economic systems to prevent an unsustainable growth trajectory. Furthermore, reducing energy consumption and controlling urban population growth are of paramount importance in fostering sustainable and green growth conditions. Policy implementations that support renewable energy production and usage, promote a sustainable economic perspective among economic agents, provide investment incentives for environmentally responsible actors, encourage participation in environmental activism, and educate society on environmental ethics and regulatory compliance could accelerate recycling processes and shift economic growth from a purely quantitative focus to a more qualitative dimension. Such policies could lay the groundwork for fostering growth that supports long-term sustainability. Finally, studies based on developed country groups, which are relatively more environmentally sensitive, can support the conclusion that the growth without a future process has been reversed.

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