Journal of Environmental Management 306 (2022) 114506

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Determinants of environmental degradation: Evidenced-based insights from ASEAN economies

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ARTICLE INFO

Keywords:
Environmental degradation
per capita income
Energy consumption
Trade openness
N-Shaped EKC
Panel data
ASEAN

ABSTRACT

This paper examines the effect of per capita income, trade openness, energy consumption, and financial development on the ASEAN region's environmental degradation. We obtained data from the World Development Indicators (WDI) during the years 2001–2020 to test our research model. For analysis, we applied panel data techniques such as pooled least squares, fixed effects, generalized least squares (GLS), and two stages least squares (2SLS). We also conducted the causality analysis to determine the direction of the relationship among the models' variables. Our models' results show the validity of the environmental Kuznets curve (EKC) hypothesis in the ASEAN region as per capita income and its square term possess positive and negative coefficients. The results also show the presence of an N-shaped EKC in ASEAN region a deviation from the conventional literature. Moreover, the results illustrate that increasing energy consumption, trade openness, and financial development positively contribute to environmental degradation in ASEAN economies. The causality analysis shows a two-way causality between trade openness and financial development, and environmental degradation and trade openness. We observed oneway causality, running a) from energy consumption and per capita income towards financial development, b) from per capita income towards trade openness, and c) from financial development towards environmental degradation. The study's results contribute to the environmental degradation literature and provide a better understanding of environmental degradation for policymakers in ASEAN economies.

1. Introduction

Empirical evidence (Neague, 2020) shows that greenhouse gas emissions (hereafter referred to as GHGs) increase environmental degradation and cause global warming. GHGs are growing at an annual rate of 1.5% (EGP, 2019). Increased CO_2 emissions are one of the main driving forces behind global warming (IPCC, 2018). These emissions also degrade the environment, producing adverse economic consequences (Ahmad et al., 2019). Environmental degradation raises poverty levels, increases infectious diseases, generates extreme weather conditions, and relentlessly affects natural diversity (Living Planet report, 2020; WHO report, 2019; Donohoe, 2003).

Rising CO_2 emissions is challenging for the "Association of Southeast Asian Nations (ASEAN)" economies, which face environmental degradation challenges despite abundant natural resources and strong economic performance. Lean and Smyth (2010) reported that ASEAN economies' rapid economic growth increased fossil fuel consumption, leading to higher pollution and CO_2 emissions levels. Current studies (Jian et al., 2019; Afridi et al., 2019) accentuate that growing energy consumption has increased environmental degradation. Hence, the rising CO_2 emissions have made the ASEAN region increasingly vulnerable to climate change challenges (Sandu et al., 2019).

Prakash (2018) suggests that CO2 emissions have increased faster in ASEAN countries between 1990 and 2010 than in the World. Since 1960, the average temperature has raised primarily due to global warming (between 0.14°C and 0.20 °C) in ASEAN region countries, resulting in substantially warmer days and nights (ADB, 2015). In 2013, the ASEAN region was responsible for 3.6% of global GHGs owing to higher economic growth and population increases (Chontanawat, 2018). Economic growth has raised the deforestation rate, which has led to the rapid depletion of natural capital. The fifth environmental report of the ASEAN economies (SOER5, 2017) confirmed that rising energy consumption was primarily responsible for increased CO2 emissions and was forecasted to increase by 61% from 2014 to 2025. Asian

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https://doi.org/10.1016/j.jenvman.2022.114506
Received 22 August 2021; Received in revised form 1 January 2022; Accepted 12 January 2022
Available online 17 January 2022
0301-4797/

Development Bank (2015) predicts that the energy sector GHGs will increase by 300% by 2050 in the ASEAN economies.

Despite extensive improvements in the economic performance of ASEAN countries, the research remains vague regarding the environmental quality (Ehigiamusoe, 2020), which provides the prime motivation for this study. First, this study examines the effect of per capita income, financial development, energy use, and openness to trade on environmental degradation. Next, it discusses the traditional Environmental Kuznets Curve (EKC) and the possibility of an N-shaped EKC in the ASEAN economies. Research suggests that the inverted U-shaped EKC may not remain valid (de Bruyn et al., 1998), and hence, there is a need to explore the N-shaped EKC in the ASEAN context. The N-shaped EKC is a relatively new phenomenon in environmental degradation research, and researchers recently investigated it (e.g., Afridi et al., 2019; Allard, 2017). Finally, we employ the causality approach (Dumitrescu and Hurlin, 2012) to explore the potential direction of relationships between variables.

The paper contributes to the concerned literature in several ways. First, it provides fresh and comprehensive evidence on the determinants of environmental degradation in ASEAN economies. Second, it examines the potential N-shaped EKC, an unexplored phenomenon in the ASEAN region. This investigation represents a departure from the conventional inverted U shaped EKC, and we assume that our findings will provide significant insights for policymakers in the ASEAN economies. Third, the current study explores the direction of relationships between the variables. Lastly, the study discusses possible consequences for future ASEAN generations and each AMS (ASEAN Member State) government's environment protection policy measures.

The rest of the paper is as follows. A comprehensive literature review is presented in section 2. Section 3 presents the descriptive statistics of individual ASEAN economies and the chosen sample. Section 4 covers the modeling and estimation methods, and section 5 explains the results. Sections 6 and 7 presents the sensitivity analysis and the causality analysis. Section 8 covers discussion, how shared socioeconomic pathways (SSPs) provide guidelines for ASEAN future generations, current environmental degradation mitigating policies of ASEAN economies. Conclusion and limitations are described in section 9.

2. Literature review

Multiple factors are responsible for environmental degradation (Jan et al., 2021A; Shah et al., 2021). For instance, rapid industrialization is considered the leading cause of environmental degradation as it utilizes natural resources to generate economic growth (Chakravarty and Mandal, 2020). Studies (Jian et al., 2019; Afridi et al., 2019; Al-Mulali and Sab, 2012) emphasize that energy consumption causes environmental degradation, especially in emerging economies undergoing rapid industrialization. Ahmad et al. (2019) established that environmental degradation is associated with higher energy consumption and economic growth in China. Likewise, the rapid industrialization and economic development of ASEAN economies have substantially increased energy consumption (Ehigiamusoe, 2020).

Studies (Jian et al., 2019; Pata, 2018) have integrated financial development into their research models to examine its potential impact on environmental degradation. However, rapid economic growth may attract FDI (foreign direct investments) inflows from developed countries, including efficient green technologies and minimizing environmental degradation. Hence, creating a sound financial system is needed to reduce emissions and higher growth (Jan et al., 2021B; Azhar et al., 2021). Research (Jian et al., 2019; Pata, 2018) shows a positive linkage between economic growth and environmental degradation in China and Turkey. In contrast, Destek (2019) posited that overall financial development is inversely related to environmental degradation in emerging economies.

Environmental degradation is also dependent on trade openness. Early research (e.g., Grossman and Krueger, 1991) acknowledges that the impact of international trade on environmental degradation depends on the scale, the composition, and the production technologies employed. According to Liobikienė and Butkus (2019), the scale effect shows that a massive increase in the production of goods and services increases inputs usage, resulting in higher pollution levels. The composition effect refers to the situation where the economic structure changes in favor of reduced polluting activities (Liobikienė and Butkus, 2019). Finally, the production technologies effect suggests that adopting new, cleaner technologies alters the expected emission levels (Ramos et al., 2017). However, empirical research indicates a varied relationship between trade and CO2 emissions. Halicioglu (2009) provided empirical evidence about the positive influence of trade on environmental degradation in the Turkish economy. Tachie et al. (2020) acknowledge that trade positively impacts environmental degradation through the scale and composition effects, and the production technologies effect has a negative impact. Recent empirical studies (Nguyen et al., 2021; Nasir et al., 2021) show that trade causes environmental degradation. In contrast, other studies (e.g., Afridi et al., 2019) show that trade negatively influences environmental degradation in emerging economies.

Grossman and Krueger (1991) proposed the environmental Kuznets curve (EKC) for identifying economic growth linkage with environmental degradation. Researchers have extensively used this framework to measure environmental degradation. Rahman et al. (2020) suggests that under the EKC hypothesis, economic growth initially worsens the environment, but over time, improves the environment. This study further confirmed the validity of the EKC hypothesis in China and India, both with and without structural breaks. Using data from East African economies, Beyene and Kotosz (2020) reported a bell-shaped EKC and concluded that income growth is not responsible for environmental degradation. However, recent studies (Afridi et al., 2019; Allard, 2017; Ahmad et al., 2019) have demonstrated the presence of an N-shaped EKC that suggests that growth initially increases environmental degradation, then diminishes it before subsequently increasing it again. Table 1A presented in the appendix section summarizes the literature on the EKC hypothesis.

The inconsistent findings in Table 1A illustrate that the traditional inverted U-shaped EKC is open for examination, and the exact shape of an EKC remains undetermined. Consequently, we explore the potential N-shaped EKC in the ASEAN context. Further, we also examine the impacts of energy consumption, trade openness, and financial development on environmental degradation.

3. The ASEAN countries and description of data

Ten Southeast Asian economies: "Brunei Darussalam, Cambodia, Indonesia, Malaysia, Myanmar, Lao People's Democratic Republic, Philippines, Singapore, Thailand, and Vietnam" established ASEAN as a trading block in 1967. According to ASEAN statistical leaflet (2020), the ASEAN region covers 4.5 million square kilometers having a total population of 655.9 million. The ASEAN region's combined GDP is around US$ 3.2 trillion, while per capita GDP is US$ 4827.4 (current prices). The ASEAN region's total trade volume in 2019 is US$ 2815.2 billion with a trade to GDP ratio of 88.9%, which is quite reasonable when compared to other areas of the world such as South Asia. In 2019, the overall ASEAN region GDP growth rate was 4.6%. However, such high growth rates and other material improvements have posed various challenges, including increasing environmental degradation in the ASEAN region. Ehigiamusoe (2020) underscored the gains achieved by ASEAN countries and suggested that the impact of economic progress on ecological degradation in AMS remains undetermined due to the lack of research. This lack of research in the ASEAN economies is one of the critical motivations for this study.

Table 1 presents the trends of chosen variables from the ASEAN economies during 2001–2020. Data is averaged both for the initial year (2001) and final year (2020) for the whole sample. The term 'CO2'

Table 1
Descriptive statistics (whole sample).

Variables	2001	2020	% Change
CO_2	4.632	5.279	13.968%
ENG	2104.368	2596.604	23.391%
FD	61.082	93.695	53.392%
TOI	145.254	134.028	−7.728%
PCI	10542.160	14580.970	38.311%

Source: Authors calculations from the World Development Indicator's data (WDI)

represents CO2 emissions and is used as a proxy for environmental degradation and is measured in "metric tons per capita." 'ENG' stands for energy consumption proxied by "total energy use (kg of oil equivalent per capita)." The term 'FD' represents financial development, measured by "domestic credit to the private sector (as a % of GDP)." 'TOI' indicates the trade openness of countries and is calculated as "trade as a % of GDP." Finally, 'PCI' represents per capita GDP and illustrates the income level in ASEAN economies in US $.

Table 1 shows that CO2 emissions have increased from 4.632 to 5.279 metric tons per capita in the ASEAN region, which shows an alarming net increase of 13.968% between 2001 and 2020. During the same period, energy consumption and development increased 23.391% and 53.392%, respectively, in the ASEAN region. Financial development, which was 61.082% of total GDP in 2001, has risen to 93.695% of total GDP in 2020.

Conversely, in the case of trade openness, global economic integration has declined in the ASEAN region by approximately 7.728% between 2001 and 2020. The trade openness index, which stood at 145.254% of GDP in 2001, decreased to 134.028% by 2020. Finally, the ASEAN region has shown remarkable improvement in terms of per capita GDP, increasing from US$10,542.160 in 2001 to US$14,580.970 in 2020 (in constant US$), showing a net increase of 38%.

Table 2 provides country-specific descriptive statistics. Brunei Darussalam has the highest per capita CO2 emissions among ASEAN members, measuring 18.597 metric tons per capita, showing an increase of 40.322% compared to 2001. In 2020, Singapore and Malaysia also produced significant CO2 emissions, measuring 8.941 and 7.982 metric tons per capita, respectively. In comparison, Singapore reduced its CO2 emissions by 25.317% in the same period. CO2 emissions in Malaysia have radically increased by 39.545%. The level of CO2 emissions has also risen in Thailand, followed by Vietnam and Indonesia. The highest increase in CO2 emissions during 2001–2020 was measured in Cambodia, followed by Vietnam. Despite this, Cambodia's CO2 emission levels are still deficient in comparison to all other ASEAN economies.

Concerning energy consumption, Brunei Darussalam leads the ASEAN region. The current energy consumption in Brunei Darussalam is 8460.589 "kg of oil equivalent per capita", which is 30.308% higher than the 2001 levels. Singapore's current energy consumption level is the second highest in the ASEAN region. However, Singapore's energy consumption has reduced between 2001 and 2020, indicating that switching to cleaner and renewable energy sources boosts economic growth without damaging environmental quality. Malaysia and Thailand are consuming a significant amount of energy to achieve their economic growth targets. The current energy consumption of Malaysia is 37.092% higher than in 2001. Thailand's energy consumption has increased by over 67% between 2001 and 2020. Cambodia has the lowest energy consumption among the ASEAN economies. The energy consumption of the Philippines declined by 3.732%.

Cambodia and Vietnam are the leading countries of the ASEAN region that have made substantial progress concerning the financial development sector. In 2001, the share of financial development in Cambodia's GDP was only 5.987%, which increased to 99.986% by 2020, showing a net increase of 1570.051%. The financial development share in Vietnam's GDP grew from 39.290% to 133.923% during

Table 2
Description of statistics (Country-specific).

Country	Variables	2001	2020	% Change
Brunei Darussalam	CO_2	13.253	18.597	40.322%
	ENG	6492.724	8460.589	30.308%
	FD	53.633	38.784	−27.686%
	TOI	108.718	110.197	1.360%
	PCI	36171.81	30717.95	−15.077%
Cambodia	CO_2	0.181	0.566	212.707%
	ENG	276.504	406.173	46.895%
	FD	5.987	99.986	1570.051%
	TOI	113.743	126.342	11.076%
	PCI	453.969	1374.579	202.791%
Indonesia	CO_2	1.375	1.956	42.254%
	ENG	742.97	872.424	17.423%
	FD	18.155	33.154	82.616%
	TOI	69.793	33.19	−52.445%
	PCI	2191.574	3756.907	71.425%
Malaysia	CO_2	5.72	7.982	39.545%
	ENG	2145.964	2941.948	37.092%
	FD	127.232	134.110	5.405%
	TOI	203.364	116.503	−42.712%
	PCI	6890.364	10616.85	54.082%
Philippines	CO_2	0.891	1.14	27.946%
	ENG	480.604	462.667	−3.732%
	FD	36.265	51.89	43.085%
	TOI	84.9	58.174	−31.479%
	PCI	1683.316	3269.671	94.239%
Singapore	CO_2	11.972	8.941	−25.317%
	ENG	5145.886	5007.888	−2.681%
	FD	115.018	132.678	15.354%
	TOI	349.292	320.563	−8.224%
	PCI	32597.64	58056.81	78.101%
Thailand	CO_2	2.906	4.12	41.775%
	ENG	1170.744	1958.152	67.257%
	FD	93.078	125.033	34.331%
	TOI	120.268	97.929	−18.574%
	PCI	3544.442	6199.191	74.898%
Vietnam	CO_2	0.757	2.002	164.464%
	ENG	379.546	663.076	74.702%
	FD	39.29	133.923	240.857%
	TOI	111.955	209.323	86.970%
	PCI	804.198	2655.768	230.238%

Source: Authors own calculations from the World Development Indicator's data

2001–2020, showing an outstanding upsurge of more than 240%. Compared to the 2001 figures, the level of financial development in Malaysia increased slightly by 5.405%, not a good sign for the country's economic growth prospects. During this period, Brunei Darussalam's financial development level has decelerated by more than 27%, indicating the poor performance of the financial sector in the country's economic growth and development. Although the Indonesian economy has improved its financial development during 2001–2020, yet has one of the lowest positions among ASEAN economies.

The country-specific statistics on trade openness are not very positive in the ASEAN region. Except for Cambodia, Vietnam, and Brunei Darussalam, trade openness declined in the rest of the ASEAN economies during 2001–2020. The trade openness index of Indonesia, Malaysian, and the Philippines declined by 52.445%, 42.712%, and 31.479%, respectively. The trade openness of Thailand and Singapore declined by 8.574% and 8.224% during 2001–2020. However, the trade openness index for Vietnam, Cambodia, and Brunei Darussalam has increased by 86.970%, 11.076%, and 1.360%, respectively. Nevertheless, the current statistics show Singapore as the most open economy, while Indonesia is the most closed economy in the ASEAN region.

During 2001–2020, the per capita income of all ASEAN region countries improved except Brunei Darussalam, which experienced a decline of more than 15%. Singapore has the highest per capita income of US$ 58,056.810 (in constant terms) in the ASEAN region, Brunei Darussalam, which has a per capita income of US$ 30,717.950 (in constant terms). Malaysia and Thailand also have reasonable per capita incomes. Vietnam has achieved a remarkable improvement in its per capita income, followed by Cambodia. Vietnam and Cambodia still have the lowest per capita incomes among the ASEAN member economies.

Fig. 1 provides an overview of the percentage change in the selected variables of the ASEAN economies. Due to its high observed value (see Table 2), changes in the financial development of Cambodia are not presented.

4. Modeling and estimation methods

4.1. Model specification

The estimation model used specifies the factors applied as the determinants of environmental degradation. Environmental degradation is affected by several factors such as energy consumption, trade openness, financial development, and per capita income. Ample empirical evidence shows the relationship between the mentioned independent variables and environmental degradation (Pata, 2018; Afridi et al., 2019; Yasin et al., 2021; Pandey et al., 2020). For the ASEAN region's economies, we use the following functional form to identify the determinants of environmental degradation.

$$co_2 = f\left(eng^a, toi^b, fd^c, pci^d, pci^{2e}\right) \tag{1}$$

Model 1 shows that environmental degradation is dependent on energy consumption, trade openness, financial development, per capita income, and the square of per capita income. The small letters ($^{a\text{-}e}$) denote the respective share of each variable in environmental degradation. Natural logarithmic transformation is applied to tackle the problem of potential non-linearities in the relationship between the dependent and independent variables. Hence, model 1 is transformed as follows:

$$\mathrm{lnco}_{2,i,t} = \beta_0 + \beta_1 \mathrm{lneng}_{i,t} + \beta_2 \mathrm{lntoi}_{i,t} + \beta_3 \mathrm{lnfd}_{i,t} + \beta_4 \mathrm{lnpci}_{i,t} + \beta_5 \mathrm{lnpci}^2{}_{i,t} + \mathrm{U}_{i,t} \tag{2}$$

In model 2, environmental degradation is captured through the natural logarithm of carbon emissions (lnCO_{2t}). Energy consumption (lneng_t) is measured by the "total energy use (kg of oil equivalent per capita)" while trade openness (lntoi_t) is approximated by the total "trade (as a % of GDP)". Similarly, "domestic credit to the private sector (as a % of GDP)" is used as a proxy for financial development (lnfd_t). Per capita income (lnpci_t) is used in constant prices. The square term of per capita income ($\mathrm{lnpci}^2{}_t$) in expression 2 is included to examine the presence of our EKC hypothesis in the ASEAN region. For the environmental Kuznets curve (traditional U-shaped), we hypothesize that the coefficients of per capita income and the square of per capita income must be positive and negative, respectively ($\beta_4 > 0, \beta_5 < 0$). The proposition developed to test the EKC hypothesis is supported by prior studies (Ahmad et al., 2019; Afridi et al., 2019).

The inverted U-Shaped EKC may not hold for some countries (de Bruyn et al., 1998), which is our prime motivation to examine the

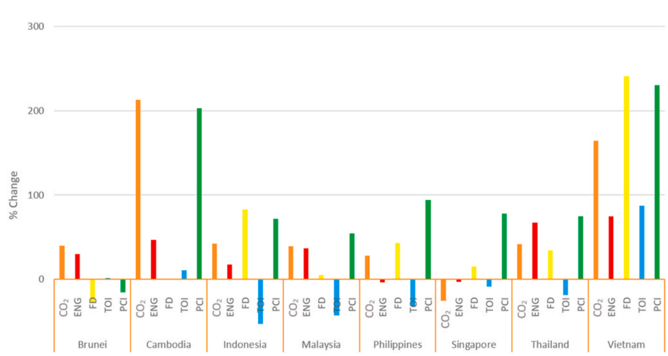

Fig. 1. Percentage Changes in the ASEAN selected variables between 2001 and 2020.

presence of an N-shaped EKC. Recent studies (Ahmad et al., 2019; Afridi et al., 2019, Allard, 2017) have examined this relationship. Hence, we included the cubic term of income per capita in model 2 to explore the potential for an N-shaped EKC in the ASEAN region.

$$\mathrm{lnco}_{2,i,t} = \beta_0 + \beta_1 \mathrm{lneng}_{i,t} + \beta_2 \mathrm{lnfd}_{i,t} + \beta_3 \mathrm{lntoi}_{i,t} + \beta_4 \mathrm{lnpci}_{i,t} + \beta_5 \mathrm{lnpci}^2{}_{i,t} + \beta_6 \mathrm{lnpci}^3{}_{i,t} + \mathrm{U}_{i,t} \tag{3}$$

To prove the N-shaped EKC for ASEAN economies, the coefficients of per capita income and the square of per capita income must be positive and negative, respectively, while the coefficient of the cubic term of per capita income should be positive ($\beta_4 > 0, \beta_5 < 0, \beta_6 > 0$). The proposition hypothesized about the N-shaped EKC is consistent with prior literature (Ahmad et al., 2019; Afridi et al., 2019). The analysis of the models mentioned above was using carried out by using EViews 9.0 econometric software.

4.2. Data and sample

It is essential to ensure data reliability, specifically in applied research studies mentioned in the previous literature (Tahir and Alam, 2020). All the independent and dependent variables data have been extracted from the "World Development Indicators" (WDI). WDI is a well-known reliable data source that provides researchers with accurate and accessible data on broad economic indicators. The period of the study ranges from 2001 to 2020. Appendix Table 2A tells about the construction of the chosen variables. In the first step, we considered all ASEAN members. In the second step, we dropped Myanmar and Lao PDR due to data inconsistency and the non-availability of data for the chosen variables. The names of the sample countries are presented in the appendix section (Appendix Table 3A).

4.3. Estimating methodology

It is crucial to employ the correct empirical methods for a specified model to obtain meaningful statistical outcomes (Jan et al., 2019; Tahir et al., 2020). The panel data collected from WDI to estimate the equation poses various challenges for researchers because of its time and cross-sectional dimensions. Due to the time dimension, heteroscedasticity, and heterogeneity issues, panel data normally suffer from autocorrelation issues. Therefore, Worrall (2010) recommended that researchers use fixed and random effects modeling as the two main estimating tools. According to Gujrati (2004), the intercept may vary across cross-sectional units in fixed effects modeling. Still, the intercept remains constant over time. In the random-effects model, the intercept represents the average value of all cross-sectional intercepts. Fixed effects modeling also works efficiently when the chance of serial correlation is present between the independent regressors and disturbance term. Likewise, random effects correction modeling is suitable if the error term and independent regressors are separate. Worrall (2010) raised the same point and suggested that the random-effects model is efficient if there is zero correlation between the independent regressors and the disturbance term. Hill et al. (2011) recommend applying the fixed effects approach to estimate panel data models. The fixed effects (equation (4)) and random effects (equation (5)) estimators are specified below.

$$y_{it} = (\alpha + u_i) + X_{it}^{/}\beta + v_{it} \tag{4}$$

$$y_{it} = \alpha + X_{it}^{/}\beta + (u_i + v_{it}) \tag{5}$$

The Hausman test (1978) is extensively used in the empirical literature to choose between fixed and random effects estimators (Worrall, 2010). The null hypothesis in the framework of the Hausman test shows that random effects are consistent and efficient compared to fixed effects estimators. The fixed effects estimator will be used if the null hypothesis is not accepted. The Hausman test is presented in the following expression 6.

$$LM = (\beta_{LSDV} - \beta_{RandomL})\, W^{\hat{-}1}\, (\beta_{LSDV} - \beta_{RandomL}) \sim \chi^2(k) \tag{6}$$

We have employed the Hausman test because it supports using the fixed effects estimator as the null hypothesis is not accepted (see Appendix Table 4A). The cross-sectional dependency test is also utilized, and its results are presented in the Appendix (Table 5A). The results indicate that the null hypothesis is accepted. Therefore, the specified models 2 and 3 are estimated by following the procedure of fixed effects modeling.

Moreover, we have also used other estimators, such as the Generalized Least Squares (GLS) and Two-Stage Least Squares (2SLS) estimators, to estimate models 2 and 3. The logic behind using the GLS estimator is that it can test the sensitivity of the fixed effects results (Chen and Gupta, 2009; Tahir and Alam, 2020). On the other hand, the 2SLS addresses the potential endogeneity problem. In the 2SLS estimation, lagged values of regressors are used as following the previous literature as instruments (Tahir and Alam, 2020). The specified models 2 and 3 are initially estimated through the pooled least squares (PLS), the starting point for panel data analysis. Results are depicted in columns 2 and 3 of Table 3. The fixed effects estimation results using the Hausman test are presented in columns 4 and 5 of Table 3.

5. Results and discussion

Our PLS results indicate a positive impact of increasing energy consumption, financial development on environmental degradation. Trade openness appears to be inversely related to environmental degradation. Column 2 of Table 3 also provides evidence for the conventional inverted U-Shaped EKC in the ASEAN region. The results show that the coefficients of per capita income and the square of per capita income are positive and negative, respectively. The results indicate the presence of N-shaped EKC as the coefficient of cubic term of per capita income is both positive and significant. However, we do not focus on these findings as the PLS technique is inappropriate based on the Chow test (1960) of poolability (see Table 6A in the Appendix).

The fixed effects result show that increasing energy consumption has had a positive and significant relationship with environmental degradation ($\beta1 = 0.507$, $S.E = 0.060$, $P < 0.001$), consistent with previous literature (Shaheen et al., 2020). Compatible with conventional wisdom and the concerned literature, it is evident that countries that consume higher levels of non-renewable energy resources have higher CO2 rates.

Table 3
Regression results.

Variables	PLS	PLS	Fixed Effects	Fixed Effects
	Coefficients	Coefficients	Coefficients	Coefficients
$lneng_{i,t}$	0.869***	1.030***	0.507***	0.595***
	(0.048)	(0.060)	(0.060)	(0.069)
$lnfd_{i,t}$	0.190***	0.109**	0.129***	0.033
	(0.045)	(0.047)	(0.030)	(0.055)
$lntoi_{i,t}$	−0.123**	−0.046	0.170***	0.144***
	(0.057)	(0.058)	(0.039)	(0.052)
$lnpci_{i,t}$	2.144***	12.843***	2.693***	7.752***
	(0.326)	(2.624)	(0.213)	(2.654)
$lnpci^2_{i,t}$	−0.113***	−1.365***	−0.133***	−0.694**
	(0.017)	(0.305)	(0.012)	(0.293)
$lnpci^3_{i,t}$		0.047***		0.020**
		(0.011)		(0.010)
Constant	−15.322	−46.198	−17.037	−32.307
	(1.426)	(7.641)	(0.782)	(7.850)
Diagnostics	Adj-R-Squared:0.975	Adj-R-Squared:0.977	Adj-R-Squared: 0.996	Adj-R-Squared: 0.996
	Prob (F-Test):0.000	Prob (F-Test):0.000	Prob (F-Test):0.000	Prob (F-Test): 0.000

Note: The dependent variable is the natural logarithm of CO_2 emissions. (***) and (**) stands for 1 and 5 percent level of significance.

Rapid industrialization and achieving higher economic growth have exponentially increased energy consumption in the ASEAN economies. However, increased energy consumption has resulted in worsening the environment quality. Financial development has a positively ($\beta2 = 0.129$) and significantly ($P < 0.001$) effect on environmental degradation. Our results support previous studies (e.g., Pata, 2018; Jian et al., 2019) that found financial development responsible for environmental degradation.

The results also support the premise that openness to trade is positively linked with environmental degradation ($\beta3 = 0.170$, $S.E = 0.039$, $P < 0.001$). The result shows that ASEAN economies have a high propensity towards openness to international trade and the net effect of openness to trade on environmental degradation is positive. Our results also support previous studies (e.g., Chen et al., 2021).

The coefficient of the per capita income is positive and statistically significant ($\beta4 = 2.693$, $S.E = 0.213$, $P < 0.001$) while the coefficient of the square of per capita income is negative and statistically significant ($\beta5 = -0.133$, $S.E = 0.012$, $P < 0.001$). The positive impact of per capita income and the negative impact of the square of per capita income on environmental degradation reflect the validity in EKC hypotheses in the ASEAN region. Our empirical results align with the work of Pata (2018) and Pandey et al. (2020). The cubic term entered into the estimated model is positive and significant ($\beta6 = 0.020$, $S.E = 0.010$, $P < 0.05$). The positive coefficient of per capita income, negative coefficient of the square of per capita income, and the positive coefficient of the cubic term of per capita income indicate the potential relationship between growing income and environmental degradation through the N-shaped EKC. This result is distinct context and questions the validity of the traditional inverted U-shaped EKC in the ASEAN region. Our results are consistent with the findings of Ahmad et al. (2019), Allard et al. (2018), and Afridi et al. (2019). Fig. 2 below illustrates the potential shape of the EKC for ASEAN economies.

Finally, it should be noted that after the introduction of the cubic term of per capita income into the model, the direction of the relationship between other independent variables and the dependent variable did not alter. The positive and significant relationships between increasing energy consumption, trade openness, and environmental degradation remain unchanged. The sign of financial development coefficient does not change and remains insignificant. Table 3 shows that the explanatory powers of the estimated model are excellent as Adjusted R-Squared values are high. The significance of the F-Test based on probability also validates the overall robustness of the estimated models.

6. Sensitivity analysis

A sensitivity analysis of the findings presented in Table 3 is carried out in this section. Following previous literature, we have estimated the specified expressions 2 and 3 with alternative estimators, namely, GLS and 2SLS. Table 4 reports the results of the estimated models 2 and 3.

Both the GLS and 2SLS estimators validated the earlier results. The results presented in columns 2 and 4 in Table 4 endorse the EKC hypothesis in the ASEAN region as the per capita income coefficient is positive and significant. In contrast, the coefficient of the square term of the per capita income is negative and significant. Similarly, the findings

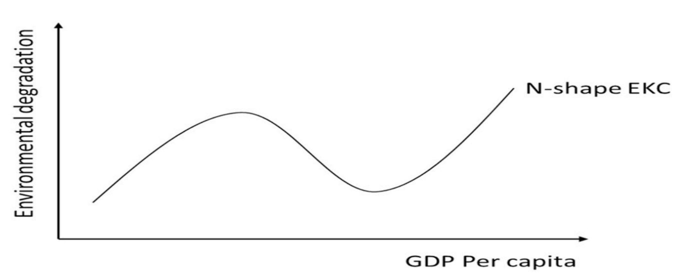

Fig. 2. Shape of the EKC in ASEAN economies.

Table 4
Sensitivity analysis.

Variables	GLS	GLS	2SLS	2SLS
	Coefficients	Coefficients	Coefficients	Coefficients
$lneng_{i,t}$	0.475***	0.448***	0.736***	0.805***
	(0.062)	(0.040)	(0.049)	(0.058)
$lnfd_{i,t}$	0.140***	0.094***	0.161***	0.058
	(0.028)	(0.017)	(0.029)	(0.047)
$lntoi_{i,t}$	0.176***	−0.127***	0.239***	0.184***
	(0.033)	(0.021)	(0.056)	(0.058)
$lnpci_{i,t}$	2.627***	6.563***	2.029***	8.290***
	(0.172)	(1.323)	(0.269)	(2.458)
$lnpci^2{}_{i,t}$	−0.129***	−0.564***	−0.097***	−0.796***
	(0.010)	(0.149)	(0.017)	(0.278)
$lnpci^3{}_{i,t}$		0.015***		0.025**
		(0.005)		(0.010)
Constant	−16.662	−27.710	−16.191	−34.431
	(0.775)	(3.810)	(1.025)	(7.169)
Diagnostics	Adj-R-Squared:0.966	Adj-R-Squared:0.982	Adj-R-Squared:0.968	Adj-R-Squared:0.996
	Prob (F-Test):0.000	Prob (F-Test):0.000	Prob (F-Test):0.000	Prob (F-Test):0.000

Note: The dependent variable is the natural logarithm of CO_2 emissions. (***) and (**) stands for 1 and 5 percent level of significance.

in columns 3 and 5 support the earlier conclusion about the potential N-Shaped EKC. Our results remain robust in both GLS and 2SLS estimation models. The positive effects of increasing energy consumption and financial development on environmental degradation remained valid in the GLS and 2SLS estimations. Similarly, the positive and significant relationship between openness to trade and environmental degradation remained unchanged in the GLS and 2SLS estimations.

7. Causality analysis

This section describes the results of the causality analysis (see Table 5). The causality analysis shows a two-way causality between trade openness and financial development. A bidirectional causality is also established between trade openness and environmental degradation. Moreover, it is found that there is one-way causality running from energy consumption and per capita income towards financial development and from financial development towards environmental degradation. Finally, a one-way causality is also observed from per capita income towards trade openness.

Table 5
Pairwise causality results.

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.
$lneng_{i,t}$ to $lnco_{2i,t}$	2.81367	0.44808	0.6541
$lnco_{2i,t}$ to $lneng_{i,t}$	3.88547	1.51524	0.1297
$lnfd_{i,t}$ to $lnco_{2i,t}$	8.13416	5.74552	9.E−09
$lnco_{2i,t}$ to $lnfd_{i,t}$	3.90390	1.53359	0.1251
$lntoi_{i,t}$ to $lnco_{2i,t}$	4.41855	2.04601	0.0408
$lnco_{2i,t}$ to $lntoi_{i,t}$	4.91413	2.53945	0.0111
$lnpci_{i,t}$ to $lnco_{2i,t}$	3.78723	1.41743	0.1564
$lnco_{2i,t}$ to $lnpci_{i,t}$	2.74241	0.37713	0.7061
$lnfd_{i,t}$ to $lneng_{i,t}$	3.26980	0.90224	0.3669
$lneng_{i,t}$ to $lnfd_{i,t}$	5.64401	3.26616	0.0011
$lntoi_{i,t}$ to $lneng_{i,t}$	2.19070	−0.17219	0.8633
$lneng_{i,t}$ to $lntoi_{i,t}$	3.10590	0.73904	0.4599
$lnpci_{i,t}$ to $lneng_{i,t}$	3.55021	1.18143	0.2374
$lneng_{i,t}$ to $lnpci_{i,t}$	2.39346	0.02969	0.9763
$lntoi_{i,t}$ to $lnfd_{i,t}$	5.46396	3.08689	0.0020
$lnfd_{i,t}$ to $lntoi_{i,t}$	4.05392	1.68296	0.0924
$lnpci_{i,t}$ to $lnfd_{i,t}$	5.37850	3.00179	0.0027
$lnfd_{i,t}$ to $lnpci_{i,t}$	3.33544	0.96759	0.3332
$lnpci_{i,t}$ to $lntoi_{i,t}$	12.1020	9.69617	0.0000
$lntoi_{i,t}$ to $lnpci_{i,t}$	2.66331	0.29837	0.7654

8. Discussion

This study provides new evidence of how increasing energy consumption, trade openness, financial development, per capita income impacts environmental degradation in the ASEAN economies. Our results endorsed the validity of the traditional U-shaped EKC hypothesis in the ASEAN region. When the cubic term of per capita income was introduced in our model, an N-Shaped EKC was detected in the ASEAN economies. The N-shaped environmental Kuznets curve shows the viable impact of sustainable economic approaches adopted among the ASEAN Member States (AMS). Financial development and trade openness also affects environmental degradation positively. Accordingly, our results suggest that the ASEAN region should increase reliance on renewable and cleaner energy sources to diminish any harmful effects of economic development on the environment. Hence, governmental officials should formulate and implement win-win strategies that create new value frameworks among AMS.

Several climate-sensitive factors such as high poverty levels, dependence on agriculture, natural resources usage, increased reliance on hospitality and tourism sectors to support livelihoods, and natural calamities dictate ASEAN economies. Given our findings, it is crucial to debate how environmental degradation would impact this region in the future. The Intergovernmental Panel on Climate Change (IPCC) recommends applying shared socioeconomic pathways (SSPs) to get a predictable description of how the future of any region may appear corresponding to emerging general global socioeconomic trends (O'Neill et al., 2016). The shared socioeconomic pathways (SSPs) framework explores future risks associated with climate change (Riahi et al., 2017). Based on projected global socioeconomic developments, five SSPs (i.e., SSP1– SSP5) describe future scenarios and then provide possible solutions to mitigate climate change challenges. Based on a society's preferences (e.g., energy consumption), SSPs can forecast future scenarios regarding greenhouse gas emissions and what actions could become effective to achieve targets agreed under the Paris Agreement (2016) and the 2021 United Nations Climate Change Conference (COP26).

Under these shared socioeconomic pathways framework, the ASCCR report (2021) states that on average, ASEAN economies need to achieve net-zero CO2 emissions by 2050 and net-zero GHG emissions by 2065 to maintain the global temperature within the 1.5–2.0 °C range. Given the ASEAN region's current socioeconomic trends and environmental mitigation policies, our study recommends following the middle of the road socioeconomic path that assumes socioeconomic and technological movements will not shift noticeably from the historical patterns (ASCCR, 2021; Riahi et al., 2017). SSPs baseline scenarios also provide possible options for future energy systems that are critical in mitigating climate change-related issues such as GHGs emissions. Consumption behavioral changes and measures such as energy-saving techniques and increased reliance on renewable energy sources can reduce emissions without compromising energy intensity and economic growth (ASCCR, 2021). Manufacturing industries, transport, change in crop land-use and forestry, and fuel combustion are the key contributors to CO2 emissions in AMS, which is likely to increase the energy demand. Therefore, it is necessary to decouple the connection between economic growth and energy-related CO2 emissions in AMS. Consequently, ASEAN economies need to develop strategies to switch from fossil fuel (i.e., coal-based energy plants) to renewable or low carbon energy sources (i.e., wind, geothermal and solar).

Currently, ASEAN block economies demonstrate sincere efforts to reduce emissions by adopting renewable (decarbonizing) energy sources to reverse the current macro-level emission trend. According to IRENA (2021), Thailand, the Philippines, and Malaysia are the leading ASEAN countries that increased their wind and solar electricity installed capacity. Further, Vietnam has risen visibly its solar electrification and offshore wind energy capacity to reduce its emission intensity. The Malaysian government has executed various policies such as green technology and national policy on climate change (2009), national automotive policy (2014), and low carbon city framework (2011) to counter emissions and climate change challenges. Even the oil-rich Brunei Darussalam is increasing its reliance on solar power and implementing stringent policies to improve energy efficiency for environmental conservation. Thailand has developed climate change master and environmentally sustainable transport plans. Vietnam is increasing its reliance on renewable energy resources to counter emissions. Further, its national climate change strategy focuses on changing industry and transportation fuel structures.

ASEAN countries are proactively focusing on energy, transport, industry, land-use, and forestry sectors to reduce emissions by 2030 (ASCCR, 2021). In addition, they are implementing policy measures in essential areas (e.g., green technology, carbon pricing, finance, prevention of air pollution, etc.) to achieve net-zero emission targets. Six ASEAN countries (Brunei Darussalam, Cambodia, Indonesia, the Philippines, Thailand, and Vietnam) are working on emission reduction targets. Singapore and Malaysia have focused on diminishing absolute emission and GHG emission intensity targets, respectively. The ASCCR report (2021) described that the Indonesian economy intends to increase renewable energy share by 23% in 2025 and 31% in 2030.

Under their respective Nationally Determined Contributions (NDCs), ASEAN economies launched climate adaptation pledges in 2020, another concrete policy measure (IGES, 2020). Brunei Darussalam, Myanmar, Singapore, and Thailand are improving forest conservation to safeguard biodiversity resources. Fighting floods and rising sea are the vulnerable areas prioritized by Brunei Darussalam, Cambodia, Malaysia, and Singapore. Cambodia, Indonesia, Lao PDR, and Vietnam are also improving urban infrastructure to combat hazards associated with rising sea levels. By building domestic and local capabilities, ASEAN economies create public resilience to deal with climate change disaster risks.

There is apparent adherence by ASEAN economies cooperate and lessen GHGs emissions through agreeable climate tools such as carbon pricing and carbon tax. ASEAN economies support introducing carbon pricing as an ambitious tool to mitigate emissions and climate change challenges (Nurdianto and Resosudarmo, 2016; Singapore Institute of International Affairs, 2020). An ASEAN-based study (Nurdianto and Resosudarmo, 2016) suggested that when carbon tax revenues are allocated fairly, carbon tax positively affects an economy. However, its impact in some economies may result in economic losses. The national social cost of carbon for Indonesia, Malaysia, the Philippines, Thailand, and Vietnam is reasonable and equitable to Singapore's current carbon tax rate, which is 5 Singapore dollars (RFF, 2020). In 2019, Singapore became the first ASEAN economy to apply the uniform carbon tax on all sectors. Indonesia imposed an environmental carbon tax on motor vehicle fuel and the power sector under a pilot project. The Philippines government has initiated energy-related tariffs in the energy sector to promote sustainable and broad economic growth. In 2019–20, Thailand introduced carbon crediting and carbon offset schemes, while Vietnam introduced environmental protection tax on products (such as gasoline, oil, petroleum, and coal) and carbon payment for forest environmental services in the forest sector.

9. Conclusion

Like other economies, the ASEAN economies are striving with the environmental degradation problems. Therefore, it is crucial to understand holistically various reasons that trigger environmental degradation. This paper empirically identifies the estimated determinants of environmental degradation in ASEAN economies by applying appropriate econometric tools using data from 2001 to 2020.

Our comprehensive empirical analysis endorsed the validity of the EKC in the ASEAN region. Financial development and trade openness also positively affects environmental degradation. One thought-provoking element of our results is that when we applied the cubic term of per capita income in our empirical model, an N-shaped EKC was detected in the ASEAN economies. The presence of the N-shaped environmental Kuznets is a significant result, emphasizing that ASEAN economies should continue to adopt aggressively environmentally sustainable approaches for comprehensive economic growth.

For ASEAN policymakers, our findings suggest that achieving economic growth with rapid industrialization processes is a proper approach as long government officials and institutions constantly monitor and ensure that such an approach does not adversely affect the quality of the environment. One way to achieve this objective by AMS is to increase the propensity to switch and adopt renewable and cleaner energy sources. This policy measure will play a key role in preserving the environmental quality without disturbing economic growth. Various quantitative scenarios of economic growth and GHGs emissions models provided by each SSP could provide a parallel approach that ASEAN economies can utilize appropriately to deal with the environmental degradation problem.

In brief, this study contributes to environmental degradation literature. It suggests that developing and implementing climate-focused policies by ASEAN economies help mitigate ecological consequences and sustain economic growth. Technological improvements and the adoption of renewable energy sources could provide avenues for lower GHGs emissions in ASEAN economies. However, the ASEAN economies are quite diverse, and therefore a one-sizefits-all strategy may not be financially feasible to contain CO2 and GHG emissions. Therefore, ASEAN policymakers need to find solutions that fit the local socioeconomic conditions.

9.1. Limitations

The study tried to provide an inclusive understanding of the determinants of environmental degradation in the ASEAN region. However, it has some limitations. First, the selected period for analysis regarding the ASEAN economies is between 2001 and 2020 as prior data is not available consistently. This period is not very extensive, and hence panel cointegration tools have not been utilized. Second, advanced methodologies for panel data such as GMM are not used due to the small cross-sectional size. Finally, it is crucial to run the applied methods in other economies as they have different resource bases and economic mechanisms, crediting this study's findings.

Credit author statement

Umar Burki introduced the idea and provided supervision. Muhammad Tahir conducted analysis and wrote introduction, literature. Umar Burki contributed to results and discussion, conclusion, implications, limitations and edited the whole draft. Both the authors approved the final version.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix. Section

Table 1
Summary of findings

Author/s	Environmental degradation proxy	Period and sample	Methods	Main findings
Pandey et al. (2020)	CO_2 emissions	1971–2014 15 Asian countries	Westerlund Cointegration	Inverted U-Shaped EKC
Dogan and Inglesi-Lotz (2020)	CO_2 emissions	1980–2014 7 European countries	Panel cointegration	Inverted U-Shaped EKC
Yasin et al. (2020)	CO_2 emissions	1996–2016 59 Less developing countries	EGLS & GMM	Inverted U-Shaped EKC
Koc and Bulus (2020)	CO_2 emissions	1971–2017 South Korea	ARDL	N-Shaped EKC
Bibi and Jamil (2020)	CO_2 emissions	2000–2018 122 Countries	Fixed and random effects	Inverted U-Shaped EKC
Afridi et al. (2019)	CO_2 emissions	1980–2016 SAARC countries	Fixed effects and EGLS	N-Shaped EKC
Ahmad et al. (2019)	CO_2 emissions	1971–2014 China	ARDL, FMOLS, GMM	N-Shaped EKC
Nazir et al. (2019)	CO_2 emissions	1970–2016 Pakistan	ARDL	Inverted U-Shaped EKC
Beyene and Kotosz (2020)	CO_2 emissions	1990–2013 12 East African countries	Pooled mean group (PMG)	Bell-Shaped EKC
Kiliç and Balan (2018)	CO_2 emissions	1996–2010 151 countries	Pooled OLS	Polynomial inverted U-Shaped EKC
Zambrano-Monserrate et al. (2018)	CO_2 emissions	1971–2011 Singapore	ARDL	Inverted U-Shaped EKC
Allard et al. (2017)	CO_2 emissions	1994–2012 74 Countries	OLS, Fixed effects, quantile regression	N-Shaped EKC
Ali et al. (2017)	CO_2 emissions	1971–2012 Malaysia	ARDL, DOLS	Inverted U-Shaped EKC
Ozturk et al. (2016)	CO_2 emissions	1988–2008 144 Countries	GMM	Inverted U-Shaped EKC
Monserrate et al. (2016)	CO_2 emissions	1960–2010 Iceland	ARDL	Inverted U-Shaped EKC
Mazur et al. (2015)	CO_2 emissions	1992–2010 28 EU countries	Fixed and Random Effects	No U-Shaped EKC
Osabuohien et al. (2014)	CO_2 emissions	1995–2010 50 African countries	Panel cointegration	Inverted U-Shaped EKC
Ahmed and Long, 2013	CO_2 emissions	1971–2008 Pakistan	ARDL	Inverted U-Shaped EKC
Shahbaz et al., 2012	CO_2 emissions	1971–2009 Pakistan	ARDL	Inverted U-Shaped EKC
Akpan and Chuku (2011)	CO_2 emissions	1960–2008 Nigeria	ARDL	Inverted U-Shaped EKC
Fodha and Zaghdoud (2010)	CO_2 emissions	1961–2004 Tunisia	Johansen Test	Inverted U-Shaped EKC

Note: ARDL: Autoregressive distributed lag, GMM: Generalized method of moments, OLS: Ordinary least squares, DOLS: Dynamic least squares.

Table 2A
Variables Description

Variables	Definition	Source
$\mathbf{lnco}_{2,i,t}$	"CO2 emissions (metric tons per capita)"	"World Development Indicators"
$\mathbf{lneng}_{i,t}$	"Energy use (kg of oil equivalent per capita)"	"World Development Indicators"
$\mathbf{lnfd}_{i,t}$	"Domestic credit to private sector (% of GDP)"	"World Development Indicators"
$\mathbf{lntoi}_{i,t}$	"Trade (% of GDP)"	"World Development Indicators"
$\mathbf{lnpci}_{i,t}$	"GDP per capita (constant 2010 US$)"	"World Development Indicators"

Table 3A
List of Countries

Country Name	Country Name
Brunei Darussalam	Philippine
Cambodia	Singapore
Indonesia	Thailand
Malaysia	Vietnam

Table 4 A
Hausman Test (Fixed and Random Testing)

"Correlated Random Effects – Hausman Test"			
Summary	Chi-Sq. Statistic	D.F	Prob.
Model-2	27.992	5	0.000
Model-3	17.868	6	0.006

Table 5 A
Cross-Sectional Dependency Test

CD Test	Statistic	d.f.	Prob.
Pesaran CD Model-2	0.666		0.5052
Pesaran CD Model-3	−0.460		0.6448

Table 6A
Poolability Testing (Redundant Test)

"Poolability Test for Model-2″	Statistic	d.f.	Prob.
"Cross-section F″	123.727	(7128)	0.000
"Cross-section Chi-square"	327.967	7	0.000
"Period F″	0.659	(19,128)	0.851
"Period Chi-square"	14.946	19	0.726
"Poolability Test for Model-3″	Statistic	d.f.	Prob.
"Cross-section F″	112.505853	(7127)	0.0000
"Cross-section Chi-square"	315.877629	7	0.0000
"Period F″	0.821624	(19,127)	0.6781
"Period Chi-square"	18.549218	19	0.4861

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