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RESEARCH ARTICLE

A technological innovation and economic progress enhancement: an assessment of sustainable economic and environmental management

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Abstract

This study examines the role of technological innovation and economic progress on environmental pollution by using STRIPAT and EKC theoretical frameworks in 25 developing Asian countries from the period 1998 to 2019. For technological advancement, the energy intensity has been used to gauge how much of the quantity of energy is employed to produce the additional unit of gross domestic product at domestic level. Therefore, the volume of the energy used in the production process is highly important as it is documented through the energy intensity. To capture the impact of innovation, the sum of total patent applications and trademark applications for the sampled countries has been used. This study applied second-generation unit root and panel cointegration techniques to estimate the results. To estimate the long-run relationship of variables and the cross-sectional interdependence, Pedroni Residual and Westerlund Cointegration tests are applied. Further, the Hausman-Taylor-type test has been used to check the efficiency of the pool mean group (PMG). The results of PMG regression confirm the existence of EKC in the developing Asian countries. The results of this study showed that technological development, innovations, and economic progress have the potential to reduce carbon emission and to protect the environment in developing Asian economies. Moreover, the results of error correction model indicate that in case of any external shock, this model will converge towards equilibrium within 64.6 years. The study proposed that a policy framework related to technological innovations should be sustained and the advancement of human capital and research and development should be the primary focus of the developing nations to mitigate the environmental challenges.

Keywords Carbon emissions · Gross domestic product · Innovations · STIRPAT · Technological advancement

JEL code Q55 · Q56

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Introduction

At the present time period, the world is confronting many problematic issues and environmental deteriorations are also one of them. Basically, climate change can be observed in many regions (Hanif et al. 2019a). In perspective of climate change, carbon dioxide is playing most important role as release in carbon emission is harming the environment. Basically, with the passage of time, industrial revolution has increased significantly and the cost of this industrial revolution envisaged in the form of environmental deterioration. Moreover, every economy of the world has the desire to increase economic growth and it also leads to create some environmental degradation (Perman et al. 2003). There are many factors which are affecting the environment and creating pollution in the form of carbon emissions (Hanif 2017).

The increase in carbon emissions results in air pollution, which is very harmful for health and causes some other health hazards (Hanif 2018a). The economic activity is highly important to cater the needs of the people, and at the same time, economic activity is also considered as the main source of creating carbon emissions (Wang et al. 2017; Bekun et al. 2019).

Economic growth is one of the main causes behind the environmental deterioration. It could be said that economic growth means more production, and for this purpose, economies must pay the cost in the form of environmental degradation. It is a reality that economic growth allows to enjoy high life style but its cost has to be paid in the form of environmental deterioration (Shahbaz et al. 2016a). Therefore, the reason behind the global warming is the growth of economies at faster rate (Acheampong 2018; Hanif et al. 2019b). But if we look towards United Nations Sustainable Development Goals (SDGs), the goal numbers 8, 13, and 15 are related to the environment and clean energy for which the nations of the world are bound to make necessary arrangements to achieve these goals.

As discussed above, the economic growth is the main cause to deteriorate the environment and the same concept is discussed in Environmental Kuznets Curve (EKC). It shows that at initial stage, economic growth caused to increase income inequality and later on economic growth caused to reduce it. The reason behind the larger the size of cake will ensure the larger share to the individuals to address the poverty. But the main point of the concern from the environment point of view is the environment degradation during the process of economic growth.

Environment quality and economic growth can be better understood by using EKC and STIRPAT frameworks. The concept of EKC stated that in start, economic growth harms environment by releasing carbon emissions, and after reaching to a threshold level, it starts protecting environment by pursuing the environment-friendly policies. In short, it means today you grow, tomorrow you clean (Nazir et al. 2018; Usman et al. 2019; Majeed and Mazhar 2020). On the other hand, STIRPAT model of environment is used to measure the impact of economic activity, population, and level of technological advancement on carbon emissions (Ibrahim et al. 2017; Liu and Xiao 2018; Yeh and Liao 2019; Kilbourne and Thyroff 2020). Therefore, the empirical validation of EKC and STIRPAT model has great significance in dealing with the matters of environment degradation.

In environmental deterioration, populations have direct role (Zhang et al. 2019; Cui et al. 2018), because more land is required for dwelling of the people and it leads to reduce the forests and green area of the world. High population also requires more resources, and if the economy is developing, then several environmental and economic issues also emerge.

In this era of advancement and technology, a highly demanded input of production process is energy because it assures the economic growth. But one of the aspects is that more energy intensity means more carbon emissions (Yang et al. 2020; Abdelfattah et al. 2018). But as the economies become developed, their energy demand becomes less because of efficiency. However, with the passage of the time, economies started to adopt the energy efficient methods of production which may lead to reduce the energy demand.

To measure the position of environmental degradation, different measures are used by different researchers. According to some researchers, to capture the environmental quality, carbon dioxide emissions prove to be a useful indicator (Khan et al. 2018; Hanif 2018c; Zhu et al. 2019). However, some researchers have used to measure environmental degradation by emissions of greenhouse gases (Liobikienė and Butkus 2017; Hanif and Gago-de-Santos 2017; Cansino et al. 2019). Moreover, ecological footprint is also used as measure of overall environmental position by some researchers (Destek et al. 2018; Liu and Xiao 2018; Dogan et al. 2019).

The study highlights how technology, innovation, economic development, and population affect the carbon emissions. Basically, these economic indicators are prerequisites to validate the environmental theory of EKC and STIRPAT framework. Furthermore, to analyze the role of innovations in order to limit the carbon releases is also the major contribution of present study. Moreover, innovations provide the efficiency in the technology which reduces environmental degradation. Therefore, this study contributes in a way that how technology and innovations impact carbon emissions in the case of emerging economies of the Asia (The information of countries available in Appendix 2: Table 11). Therefore, it could be considered as the main contribution of this study to present the role of innovations in carbon emissions.

The model considered in this research study is very useful from the research perspective as it includes the non-linear impact of economic growth along with population and technology. It may provide options for policy makers to make useful polices in the emerging economies of the world. Economic growth is the foremost objective of an economy, but at the same time, economic growth also relates to environmental degradation. As this study is considering the middle-income emerging economies of the world, therefore, the role of innovations is highly important from the environmental perspective. Once the role of innovations is empirically established in reducing the carbon emissions, certainly it will be a very good area for policy makers to make such policies to promote innovations to reduce carbon emissions.

So, the objective of this study is to analyze the existence of EKC and STIRPAT framework for the middle-income emerging economies of the world. Moreover, this study also incorporates the role of innovations by introducing an interaction term to check how innovations are playing their role for the betterment of the environment. This study also aims to propose a suitable policy in the light of the estimated results for the sampled countries. The rest of the study consists of the following sections.

A brief literature review of the empirical studies to highlight research gap is given in "Literature review". Data and methodological framework developed in "Data and methodology". Results are discussed in "Results and discussion" and conclusion with policy implication is given in "Conclusion".

Literature review

In the literature, so many studies used STIRPAT (STochastic Impacts by Regression on Population, Affluence and Technology) which are comprehensively putting light on the subject matter. The importance of undertaking this area of research is to test how environment is affected by these economic indicators.

The concept of *Environmental Kuznets Curve* has also been widely tested in the literature and there are so many studies which have empirically validated its existence. According to EKC approach, economic development firstly increases the income inequality, and later on, it reduces the income inequality (Todaro and Smith 2015). Subsequently, a lot of work has been done on the empirical validation of the subject matter. In the literature, the EKC can be classified into many categories like panel data EKC, time series EKC, N-shaped EKC, and U-shaped EKC. However, there are also some studies which are not in the favor of EKC hypothesis validation due to some of its limitations. Lau et al. (2014) investigated the validation of EKC for Malaysia by analyzing the time series data. They confirmed the existence of U-shaped EKC hypothesis. They also reported that FDI and trade liberalization are significantly causing the carbon emissions. Onafowora and Owoye (2014) conducted the study to check the validation of EKC hypothesis in a sample of eight countries of Asia. They found the existence of U-shaped EKC in Japan and South Korea. However, for the remaining six countries, the N-shaped EKC hypothesis was validated. The Ganger causality test indicates that energy consumption is causing both carbon emissions and economic growth. Ozturk and Al-Mulali (2015) investigated the impact of trade openness and urbanization on carbon emissions in case of Cambodia. They found that the trade is significantly causing the carbon emissions. They also found that in case of Cambodia, the EKC hypothesis was not validated. Azam and Khan (2016) explored the existence of EKC using time series data of different income group countries. According to the estimated results, there exists cointegration in the model. The OLS results also confirmed the existence of inverted U-shaped EKC curve in the ample countries. It was also found that the energy and trade caused to increase carbon emissions but at the same time the urbanization caused to decrease it. Marsiglio et al. (2016) have done a different job in the perspective of EKC for this purpose; they have developed standard balanced growth path analysis. They advocated that environmental deterioration takes place due to structural changes. Sinha and Shahbaz (2018) conducted the study on annual data of India to check the validation of EKC hypothesis. They found that renewable energy consumption is significantly and negatively impacting the carbon emissions. They also validated the existence of inverted U-shaped EKC hypothesis for carbon emissions. Destek et al. (2018) have used ecological footprint to check the existence of EKC. In this regard, they have selected newly industrialized countries as sample. According to the results, there exists the inverted U-shaped EKC. Moreover, the control variables like energy consumption caused to increase ecological footprint. Financial development in some countries is significantly increasing the ecological foot print in some countries while it has reverse relation in some other countries. Bekun et al. (2019) validated the existence of inverted U-shaped pattern between energy use and economic growth in the long run for time series data of South Africa taking energy use as dependent variable. Moreover, labor and capital caused to reduce energy use and carbon emissions caused to reduce energy use. Altıntaş and Kassouri (2020) have confirmed the existence of inverted U-shaped EKC for the selected European countries. The impact of fossil fuels on environment was tested, and it was found that fossil fuel energy consumption is found to be harming the environment. Ongan et al. (2020) have confirmed the existence of EKC both in actual form and in decomposition for USA. Moreover, fossil fuel and renewable energy are damaging and protecting the environment, respectively.

Zineb (2016) used the STIRPAT model for 176 countries around the globe. The basic variables/indicators of STIRPAT model are causing to increase carbon emissions. Furthermore, freedom index, trade openness, and trade development are also significantly increasing the carbon emissions. His study also confirmed the validation of EKC hypothesis. Shahbaz et al. (2016b) conducted a study on the time series data for Malaysia and have applied the structural break for the STIRPAT methodology. They also checked the nonlinearity for the urbanization and found the U-shaped relationship. Moreover, GDP and energy consumption is significantly increasing the carbon emissions but the trade openness caused to decrease it. Ibrahim et al. (2017) have applied the STIRPAT model in case of Turkish economy. For this purpose, he also applied the structural break on the data series. According to the estimated results, energy imports, carbon emissions, and financial development are the significant determinants of GDP in the long run. Abdelfattah et al. (2018) have estimated STIRPAT for the Arab region. According to the estimated results, GDP energy intensity, industrialization, and population caused to increase carbon emissions but urbanization caused to reduce it. Moreover, this study also proved the existence of inverted U-shaped EKC. Cui et al. (2018) have used the STIRPAT analysis and found that production efficiency, agricultural production, urbanization, population, agricultural machinery, and degree of opening to the outside caused to increase carbon emissions. But industry structure caused to reduce carbon emissions. Moreover, this study also proves the existence of inverted U-shaped EKC. Shi et al. (2019) have compiled the results of STIRPAT model for top ten energy consumption countries. The study results revealed that GDP, fossil fuel, and population are the main determinants which are significantly increasing the carbon emissions. However, renewable energy consumption and financial development are significantly decreasing the carbon emissions. Zhang et al. (2019) have applied STIRPAT methodology for the China. According to the estimated results, fossil energy, GDP per capita, and total population are the key determinants of carbon emissions. Liang et al. (2020) and Zhu et al. (2019) stated that role of innovation is also very important for the environment. In this regard, patent application and trade mark are useful tool to capture the extent of innovations. The reason behind is that if an economy is able enough to register patent applications and trademarks, it means that innovations are emerging. As discussed by Dinda (2018) and Mensah et al. (2019), patent applications and trademarks are considered as proxy of innovation to envisage the potential of innovation to protect the environmental degradation. Yang et al. (2020) have also confirmed that innovations reduce carbon emissions.

The missing aspect found in the literature review is to check the impact of innovations of carbon emissions with special focus on emerging economies of the world. However, a comprehensive work can be seen regarding EKC and STIRPAT, but the role of innovations in the perspective of this theoretical framework is missing in which this study is going to fulfill. In this context, this study will propose a model which contains both EKC and STIRPAT framework where innovations are added as a control variable which is also a variable of interest. As this study has used the sample of emerging economies of the world having middle-income category, in this regard, the research on role of innovations in carbon emissions may serve as addition in the stock of literature. The literature review shows the number of studies that has been conducted to validate the existence of EKC and STIRPAT model on time series and panel data of different regions. One of the important aspects that has been ignored or found in a few of the studies is the role of technology and innovation in determining the carbon emissions. Therefore, the key contribution of this study in the existing literature is to assess the importance of technology and innovations to control carbon emissions, and in addition to test the validation of EKC and STIRPAT model in the sample emerging economies.

Data and methodology

To conduct the empirical analysis, the study has employed the data of 25 developing Asian economies over the time span of 1998 to 2019. In present study, carbon emission (ENP) is used as a dependent variable, while economic progress **(**ECP) and its square **(**ECP^2), technological advancement (TAD), technological innovation (TA1), research and development expenditures (R&D), and urbanization (URB) have been employed as independent variables. All the variables are taken from the World Development Indicators (World Bank 2020). The details of the independent and dependent variables have been discussed below:

Carbon emissions (ENP): To gauge the environmental pollution, the annual rate of per capita carbon emissions in metric tons per capita has been used by following Shahbaz et al. (2016a) and Hanif (2018b). The increase in carbon dioxide emissions is closely related with economic growth, energy intensity, and urban population in the developing Asian economies.

Economic progress (ECP): This study has employed the economic growth using gross domestic product per capita for economic growth as independent variable following the studies like Özokcu and Özdemir (2017) and Hanif et al. (2020) that have also employed the same relationship. Similarly, this study also hypothesized that increase in economic growth would also lead to increase the carbon emissions.

Economic progress squared (ECP^2): The square term is introduced to capture the nonlinear impact of economic growth in this study. The square term is also used to empirically validate the EKC hypothesis. The following the studies like Özokcua and Özdemir (2017) and Destek et al. (2018) have also employed the same relationship. Similarly, this study also hypothesized that as increase in square term of the economic growth, it would also lead to decrease the carbon emissions.

Technological advancement (TAD): The energy intensity in the study measures the technological factor for STIRPAT model. The energy intensity measures how much of the quantity of energy is employed to produce the additional unit of gross domestic product. Therefore, the volume of the energy used in the production process is highly important as it is documented through the energy intensity. More energy intensity means more carbon emissions; by following the studies of Wang et al. (2013), Wu et al. (2016), and Abdelfattah et al. (2018) Arroyo et al. (2020), the current study is also incorporating the same proxy for the technological development in production process. This study also hypothesized that an increase in energy intensity may lead to increase the carbon emissions.

Technological innovation (TAI): Betterment in the technology is called innovation; to capture the impact of innovation, this study has used the sum of total patent applications and trademark applications for the sampled countries. Similarly, Mensah et al. (2019) in his study also incorporated the role of these two factors. This study also hypothesized that the innovation term has the potential to protect the environment by reducing the carbon emissions.

Research & Development (R&D): It referred as the gross domestic product expenditures that are made to promote research and development in a country. It includes all the public, private, higher education, and non-profit private organizations to promote basic and applied research.

Urban population growth (URB): The demographic variable included in the model is the urban population growth as it has very close relationship with environment. Therefore, this study has employed the percentage of urban population in total population as independent variable. Abdelfattah et al. (2018) and Zhang et al. (2019) have used this indicator. This study also hypothesized that increase in urban population would also lead to increase the carbon emissions.

Econometric methodology

This study has combined both STIRPAT and EKC framework to analyze the environmental part of EKC on carbon emissions. There are many studies which incorporate the STIRPAT and EKC framework jointly (Wang et al. 2017; Khan et al. 2018; Hanif et al. 2019a; Zhou 2019; Liang et al. 2020). The specification of STIRPAT is given in equation 1.

$$I_{it} = \delta P_{it}^{\alpha} A_{it}^{\beta} T_{it}^{\gamma} u_{it} \qquad (1)$$

Here,

I as ENP = Impact on environment by means of energy use

P as URB = population growth

A as ECP = Affluence

T as TAD = Technology or relative efficiency to produce goods

Thus, the STIRPAT model used in this study can be written as.

$$\mathrm{ENP} = f(\mathrm{URB}, \mathrm{ECP}, \mathrm{TAD}, \Phi) \qquad (2)$$

$$ENP_{it} = \beta_0 + \beta_1\, URB_{it} + \beta_2\, ECP_{it} + \beta_3\, TAD_{it} + \beta_n\, \Phi_{it} + \varepsilon_{it} \qquad (3)$$

In equation 2 and equation 3, Φ denotes the indicators like population, technological innovation, and the square of economic progress and explains the mutual specification of EKC and STIRPAT. In the literature, there are many studies which are using these variables in their econometric model; some recent are as follows: Hanif (2018b) has used economic growth and its square for EKC. Zhang et al. (2019) and Shi et al. (2019) have used population in their study. This energy intensity as proxy of technology is used by Emir and Bekun (2019) and Arroyo et al. (2020). The proposed econometric model based on STIRPAT and ECK theories is given in equation 4.

$$ENP_{it} = \beta_0 + \beta_1\, ECP_{it} + \beta_2\, ECP_{it}^2 + \beta_3\, TAD_{it} + \beta_4\, TAI_{it} + \beta_5 R\&D_{it} + \beta_6\, URB_{it} + \varepsilon_{it} \qquad (4)$$

Here, t denotes time, i denotes for countries, β_0 is the intercept, and $\beta_1 \ldots . \, \beta_6$ are the coefficients of ECP, ECP^2, TAD, TAI, R&D, and URB, respectively. However, the ε_{it} is the error term in this regression model. A number of studies have used the panel autoregressive distributive lag (ARDL) method (Li et al. 2016; Xing et al. 2017; Shaari et al. 2020). For this study, we will use the pool mean group (PMG) econometric technique.

Results and discussion

The descriptive statistics are given in Table 1. It can be observed that the value of standard deviation is less than mean value in case of each variable; this shows that the data series are under dispersed.

To identify the issue of multicollinearity in data, the results of one to one correlation between variables are identified by applying correlation matrix and results are given in Table 2. Moreover, the variance inflating factors (VIF) are also given in parenthesis.

In Table 2, the results based on correlation matrix and VIF showed that there is no problem of multicollinearity in the proposed model. In the next step, the cross-sectional dependence (CD) tests are employed to test the serial dependence between the variables and results are given in Table 3.

The different versions of CD tests are applied to test cross-sectional dependence. However, the results rejected the null

Table 1 Descriptive statistical summary

	ENP	ECP	ECP^2	TAD	TA1	R&D	URB
Mean	5.556	0.879	76.892	3.385	1.567	4.589	1.289
Median	5.864	0.216	82.325	2.729	0.537	1.706	0.388
Maximum	14.231	9.333	99.672	17.131	22.589	32.640	11.510
Minimum	−13.126	0.000	20.879	−2.757	0.000	0.000	0.000
Std. Dev.	3.764	1.624	22.248	2.988	3.540	6.718	2.033
Obs.	550	550	550	550	550	550	550

Source: Author's own calculations

hypothesis and depict the presence of cross-sectional dependence in the panels. Therefore, a most robust version of unit root test such as augmented cross-sectional Im Pesaran and Shin (CIPS) applied to identify the integration order among the dependent and independent variables, and the results are given in Table 4.

The results indicate that carbon emissions (ENP), economic progress square (ECP^2), technological advancement (TAD), and urbanization (URB) are stationary at first difference whereas economic progress (ECP), technological innovation (TA1), and Research & Development (R&D) expenditures are stationary at level. This refers to apply the cointegration test for the empirical analysis. Hence, for the long-run association among the variables, we have used the Pedroni and Westerlund residual tests of cointegration in Table 5.

The results in Table 5 show that both the Westerlund and Pedroni cointegration equations reject the null hypothesis of no cointegration. Moreover, to test the slope heterogeneity, we have used the standard delta and HAC robust test, and results are given in Table 6 (Pesaran and Yamagata 2008; Blomquist and Westerlund 2013).

Null hypothesis: homogenous slope coefficients, HAC Bartlett Kernel with an average bandwidth of 1.94

In the results of Table 6, the statistics of standard delta and the HAC robust tests reject the null hypothesis of slope homogeneity. So in this case, pooled mean group (PMG) with mean group and dynamic fixed effect with the help of Hausman type

Table 3 Cross-sectional dependence test

No. of cross-sections: 25; total number of observed unbalanced values: 524

Type of test	Statistics	*df*	Probability
Scaled LM (bias corrected)	5.04***		0.004
Scaled LM (Pesaran)	4.75***		0.000
CD Pesaran	3.67***		.0001
Pesaran and Yamagata	2.02***		0.000
LM Breusch-Pagan	345.51***	104	0.004

***1% significance level

test is the most appropriate methodology (results are given in Appendix 1: Table 9, Table 10). In both cases, we reject the alternative and accept the null hypothesis as the probability values of Hausman type test are greater than 5% critical values. The rejection of alternative hypothesis specifies that PMG is the most effective estimator. Therefore, the long-run estimates based on PMG are given in Table 7.

In Table 7, the result showed a significant positive relationship between GDP and carbon emissions in the developing Asian economies. The coefficient value 0.52 shows that a one-unit rise in GDP proliferates the carbon emissions approximately half a unit that is highly significant. The square of economic growth used to validate the existence of EKC. The coefficients of GDP and GDP^2 are revealing positive and negative sign which validated the existence of the inverted U-shaped EKC in this study. The results are consistent with the findings of Marsiglio et al. (2016), Zoundi (2017), and Altıntaş and Kassouri (2020).

The existence of U-shaped EKC represents that initially economic growth in emerging economies has increased the pollution in the form of CO_2 discharge, and after a threshold level, it tends to decrease. In this regard, the optimal value of turning point of EKC is also very important. For this purpose, the turning point of GDP was calculated at 13.040. The turning point is the level of economic growth at which carbon emissions begin to decrease as these economies may have

Table 2 Results of correlation matrix

	ENP	ECP	ECP^2	TAD	TAI	R&D	URB
ENP	1.000 (1.000)						
ECP	0.254 (1.069)	1.000 (1.000)					
ECP^2	−0.244 (1.063)	−0.381 (1.170)	1.000 (1.000)				
TAD	0.169 (1.029)	0.000 (1.001)	−0.007 (1.024)	1.000 (1.000)			
TAI	0.057 (1.003)	−0.269 (1.078)	0.150 (1.023)	0.296 (1.096)	1.000 (1.000)		
R&D	0.108 (1.012)	0.0182 (1.001)	0.214 (1.048)	−0.141 (1.020)	0.389 (1.178)	1.000 (1.000)	
URB	−0.06 (1.004)	−0.130 (1.017)	0.438 (1.238)	0.038 (1.001)	0.006 (1.002)	0.085 (1.007)	1.000 (1.000)

Note: The results of variance inflating factor (VIF) are given in parentheses

Table 4 CIPS test of unit root

			At level		At 1st difference		
Variables	Test	Lags	I	I and T	I	I and T	Conclusion
ENP	CIPS	1	−1.116	−1.473	−3.591***	−3.723***	I(1)
		2	−1.487	−2.321	−3.643***	−3.734***	
ECP	CIPS	1	−2.44***	−2.75**	--	--	I(0)
		2	−3.573***	−3.788**	--	--	
ECP^2	CIPS	1	−1.116	−1.473	−3.591***	−3.723***	I(1)
		2	−1.487	−2.321	−3.643***	−3.734***	
TAD	CIPS	1	−1.116	−1.473	−3.591***	−3.723***	I(1)
		2	−1.487	−2.321	−3.643***	−3.734***	
TAI	CIPS	1	−2.218***	−3.015**	--	--	I(0)
		2	−2.856***	−3.471**	--	--	
R&D	CIPS	1	−2.041***	−2.032**	--	--	I(0)
		2	−2.345***	−3.021**			
URB	CIPS	1	−1.654	−1.936	−3.561***	−3.415***	I(1)
		2	−1.721	−1.763	−3.731***	−3.881***	

***, **1% and 5% significance level

followed the environmental rules and regulations, and now, the focus is on other aspects instead of economic growth. More precisely, the first stage of EKC in the developing Asian economies is the revelation of the basic principle that initially economic growth is considered as the prime target in which less attention towards environment is devoted. Once the desired level of economic progresses, the preference might shift towards the adoption and implementation of environmental protection policies. In this regards, number of possible measures can be taken by the emerging economies to sustain the environment by adopting the measures of environmentally safe production processes. Consequently, it leads to sustainable economic growth in which the economic growth is achieved by protecting the environment on sustainable basis.

Energy intensity is used in the model that measures how much of the quantity of energy is employed to produce the additional unit of gross domestic product. The significant and positive coefficient value of energy intensity is 0.204 demonstrating that 1% increase of energy intensity increases carbon releases by approximately 20% in the developing Asian economies. The relationship of energy intensity and carbon emissions reveals that energy intensity caused to damage the

Table 5 Westerlund and Pedroni residual cointegration Tests

No. of Cross-sections: 25; parametric (ADF) and non-parametric (PP) test				
	Statistics	**Probability**	**Weighted Stats.**	**Probability**
	−0.073	0.529	−2.935	0.998
Panel ADF	−1.843**	0.077	−2.205**	0.020
Panel rho	1.348	0.835	2.472	0.943
Panel PP	−6.673***	0.001	−3.974***	0.003
Individual AR coefs. (between-dimension): alternative hypothesis				
	Statistics	**Probability**		
Group ADF	−2.534**	0.056		
Group rho	2.893	0.002		
Group PP	−6.795***	0.000		
Westerlund test of cointegration				
Null hypothesis: no cointegration			Number of cross-sections = 25	
Alternate Hypo.: some panels are cointegrated			Number of time = 22 years	
Panel specific cointegration vector:			Trend of time: not included	
Trend assumption: No deterministic trend			Cross-section specific AR parameter	
	Statistics		Prob. value	
Variance ratio (VR)	−2.438**		0.032	

***, **, *1%, 5%, and 10% significance level

Table 6 Standard delta and HAC robust tests: results

The standard delta test	
Delta value	**Prob. value**
5.63	0.000
6.62 (adj.)	0.002
Null hypothesis: homogenous slope coefficients	
The test of HAC robust	
Delta value	**Prob. value**
6.58	0.000
8.52 (adj.)	0.005

environment (Wang et al. 2013; Shahbaz et al. 2015; Abdelfattah et al. 2018). The higher the use of energy in production process increases the carbon emissions. The production process or increased gross domestic product is the top priority in developing countries; the energy intensity increases the carbon emissions. It is also evident from the case of emerging economies that they prefer to increase the economic growth, whether what the quantum of energy is used in the production process. The results clearly indicate that the emerging economies have to look into the matter and introduce such production policies that may help in reducing the energy intensity level.

The coefficient of urban population growth (URB) is 0.15 that is positive and significant at 10%: meaning that 1% growth in urban population enhances the carbon releases by 15% in the developing Asian countries. The increasing pressure of urban population in developing Asian economies requires more resources for feeding and dwelling, which ultimately results in the environmental degradation. Therefore, the increasing population creates environmental concerns in the form of different pollutants in the emerging economies. The total population is also tending to damage the environment (Zhang et al. 2019; Yeh and Liao 2019; Cui et al. 2018). The case of developing Asian economies is quite clear as the urban population is rising over the time, and ultimately, this rising population is causing the environmental degradation. The results provide an insight about the population planning to be required at large scale to protect the environment in efficient manner. In emerging economies, the population needs to be planned in such a way that its adverse environmental impacts could be minimized.

Table 7 Results of pool mean group (PMG) for long-run coefficients

Dependent variable: D. Carbon emissions (ENP)

Variables	Coefficients	z-stat.	Std. Err.	*p* value
Eco. Progress (ECP)	0.412***	3.45	0.345	0.022
Eco. Progress (ECP^2)	−0.082***	2.32	0.054	0.042
Tech. Advancement (TAD)	0.313***	3.92	0.034	0.001
Tech. Innovation (TA1)	−0.055	0.39	0.067	0.036
Exp. Research and Dev. (R&D)	−0.421***	4.45	0.089	0.002
Urbanization (URB)	0.214*	1.65	0.052	0.094

***, **, *1%, 5%, and 10% significance level

Table 8 Results of ECM-based PMG

Dependent variable: D. Carbon emissions (ENP)

	Coef.	z-stat.	Std. Err.	*p* value
ECT	−0.646***	−10.00	0.064	0.000
Eco. Progress (ECP) D1	12.808	0.36	35.456	0.718
Eco. Progress (ECP^2) D1	0.107	0.17	0.640	0.867
Tech. Advancement (TAD) D1	0.189	1.51	0.124	0.130
Tech. Innovation (TA1) D1	−17.348	−0.89	19.570	0.375
Exp. Research and Dev. (R&D) D1	−23.990	−0.89	26.921	0.373
Urbanization (URB) D1	4.457	0.93	4.771	0.350
Constant	−1.581**	−1.93	0.821	0.054

***, **, *1%, 5%, and 10% significance level

The compound variable technological advancement (TAD) based on patent and trademark applications has been used to assess the impact of innovations on carbon emissions. The innovations always found to reveal a good impact on the environment because it caused to improve in the technology which increases the production efficiency (Dinda 2018; Mensah et al. 2019; Lin and Zhu 2019). This study also has the same finding as 1% increase in innovations causes to decrease in carbon emissions by 0.002% significantly. Innovations refer to the improvement in the efficiency of the production process. As over the time period the inventions take place, certainly it improves the efficiency in terms of the cost of production and environmental protection. The increased number of inventions with the specific focus on environment-friendly products plays its role in protection against the environment degradation. In this regard, the estimated results of innovations for emerging economies indicate the potential of managing the carbon emissions by improving the level of innovations. For this purpose, it is highly important to develop the culture of promoting innovations in production process with specific focus on introducing the echo patents rather than the commercial patents.

The research and development's (R&D) coefficient value is −0.33, which is also significant and shows an effective negative contribution to carbon emission growth in developing Asian economies. The results are in line with Lee and Min (2015), Churchill et al. (2019), and Huang et al. (2020). PMG findings have revealed the prolific influence of technological advancement, R&D, energy intensity, economic growth, and urban expansion on long-term carbon emissions in developing

Asian countries. The short-run estimates based on PMG are given in Table 8 and country-wise results are given in Appendix 1 (see Table 11).

The findings in Table 8 depict the correct negative sign of error correction term that is negative and also significant at 1% level. Thus, the negative sign of ECT coefficient shows that the model has the tendency to converge from short to long run with the speed of 64.6% per year.

Conclusion

The study empirically validates the existence of STIRPAT and inverted EKC model in emerging economies of the world. The existence of inverted shape EKC hypothesis shows that in emerging economies of the world, the economic growth causes carbon emissions at first stage, and then subsequently in second stage, the economic growth reduces the carbon emissions. The early stages of economic development, energy intensity, and the growing urban population of developing Asian economies are directly related with the creation of carbon emissions. Furthermore, the rising economic activity after a certain level, technological innovations, and R&D plays an important role in reducing the carbon emissions. One of the important features of the developing Asian economies is the growing pace of economic growth which requires energy consumption. The high concentration and connectivity of infrastructures in urban areas of Asian economies is a major cause to environmental degradation Thus, we must seek the alternative opportunities for structural transformations of the urban system to reduce the population pressure from cities. A better urban policy and planning is needed for resilient and sustainable urban population growth to protect the environment. The impact of economic growth on environment is very large and it requires that environmental friendly part be achieved as soon as possible. The technological innovations can play its role in reducing the carbon emissions. There is a need to concentrate on technological innovations and R&D activities in combination to protect clean and green environment. Some specific policies are required on the part of public regulators to promote technological innovations in production process in order to reduce the environmental degradations. The Sustainable Development Goals related to environment require to be pursued rigorously and special budget allocations must be arranged for the sustainability of Asian developing economies.

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Compliance with ethical standards

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Appendix

Table 9 Hausman test (1978) for MG and PMG

	(b) mg	(B) Pmg	(b-B) Difference	Sqrt (diag. (V_b-(V_B)) S.E.
Eco. Progress (ECP)	54.822	−0.526	55.349	72.772
Eco. Progress (ECP^2)	−0.481	0.074	−0.555	1.119
Tech. Advancement (TAD)	0.430	0.204	0.225	0.390
Tech. Innovation (TA1)	−1.763	−0.009	−1.753	9.366
Exp. Research and Dev. (R&D)	−285.258	0.065	−285.324	448.281
Urbanization (URB)	−55.109	0.337	−55.447	112.686

Test: H0: difference in coefficients not systematic

Chi^2 (6): 4.16

Prob>Chi^2 : 0.654

Decision: reject null hypothesis if p value < 0.05

Table 10 Hausman test (1978) results to compare DFE and PMG

	(b) mg	(B) Pmg	(b-B) Difference	Sqrt (diag. (V_b-V_B)) S.E.
Eco. Progress (ECP)	0.018	−0.526	0.545	0.326
Eco. Progress (ECP^2)	−0.023	0.074	−0.098	0.059
Tech. Advancement (TAD)	0.232	0.204	0.028	0.054
Tech. Innovation (TA1)	0.035	−0.009	0.045	0.106
Exp. Research and Dev. (R&D)	0.101	0.065	0.035	0.157
Urbanization (URB)	0.316	0.337	−0.020	0.031

Here, Chi^2 (6): 8.44; Prob>Chi^2 : 0.207

Table 11 (continued)

Dependent variable: D.ENP				
Independent variables	Coef.	Std. Err.	z-stat.	*p* value
Eco. Progress (ECP)	−0.341	0.406	−0.84	0.402
Eco. Progress (ECP^2)	0.135	0.123	1.10	0.272
Tech. Advancement (TAD)	−0.277	0.401	−0.69	0.489
Tech. Innovation (TA1)	−2.662	2.806	−0.95	0.343
Exp. Research and Dev. (R&D)	0.344	0.647	0.53	0.594
Urbanization (URB)	0.208	1.305	0.16	0.873
Constant	0.761	1.187	0.64	0.521
Country 7: Philippines				
Carbon emissions (ENP)	−0.871	0.208	−4.18	0.000
Eco. Progress (ECP)	−1.674	4.912	−0.34	0.733
Eco. Progress (ECP^2)	0.618	0.227	2.72	0.007
Tech. Advancement (TAD)	−0.600	0.405	−1.48	0.139
Tech. Innovation (TA1)	0.260	0.359	0.73	0.467
Exp. Research and Dev. (R&D)	−21.507	13.174	−1.63	0.103
Urbanization (URB)	−2.028	8.009	−0.25	0.800
Constant	0.170	1.643	0.10	0.917
Country 8: Thailand				
Carbon emissions (ENP)	−0.895	0.199	−4.48	0.000
Eco. Progress (ECP)	−5.534	6.183	−0.89	0.371
Eco. Progress (ECP^2)	1.000	0.925	1.08	0.280
Tech. Advancement (TAD)	−0.561	0.407	−1.38	0.168
Tech. Innovation (TA1)	103.741	49.987	2.08	0.038
Exp. Research and Dev. (R&D)	0.599	5.758	0.10	0.917
Urbanization (URB)	−0.727	2.492	−0.29	0.770
Constant	−3.457	2.531	−1.37	0.172
Country 9: Vietnam				
Carbon emissions (ENP)	−0.121	0.084	−1.43	0.153
Eco. Progress (ECP)	0.943	0.585	1.61	0.107
Eco. Progress (ECP^2)	0.090	0.069	1.30	0.195
Tech. Advancement (TAD)	0.160	0.099	1.61	0.106
Tech. Innovation (TA1)	−3.132	1.036	−3.02	0.003
Exp. Research and Dev. (R&D)	1.889	1.730	1.09	0.275
Urbanization (URB)	0.285	0.097	2.92	0.003
Constant	−0.079	0.299	−0.26	0.791
Country 10: Bangladesh				
Carbon emissions (ENP)	−0.485	0.217	−2.23	0.026
Eco. Progress (ECP)	5.153	2.706	1.90	0.057
Eco. Progress (ECP^2)	−0.021	0.176	−0.12	0.905
Tech. Advancement (TAD)	0.412	0.535	0.77	0.442
Tech. Innovation (TA1)				
Exp. Research and Dev. (R&D)	0.531	0.680	0.78	0.435
Urbanization (URB)	0.441	4.019	0.11	0.913
Constant	0.391	1.056	0.37	0.711
Country 11: Bhutan				
Carbon emissions (ENP)	−0.485	0.137	−3.54	0.000
Eco. Progress (ECP)	0.702	0.660	1.06	0.288
Eco. Progress (ECP^2)				

Table 11 PMG estimate

Dependent variable: D.ENP				
Independent variables	Coef.	Std. Err.	z-stat.	*p* value
Country 1: Cambodia				
Carbon emissions (ENP)	−0.566	0.107	−5.28	0.000
Eco. Progress (ECP)	−1.458	0.383	−3.81	0.000
Eco. Progress (ECP^2)	0.862	0.173	4.96	0.000
Tech. Advancement (TAD)	−0.151	0.165	−0.91	0.360
Tech. Innovation (TA1)	--	--	--	--
Exp. Research and Dev. (R&D)	--	--	--	--
Urbanization (URB)	--	--	--	--
Constant	2.343	1.012	2.31	0.021
Country 2: China				
Carbon emissions (ENP)	−0.451	0.126	−3.58	0.000
Eco. Progress (ECP)	1.242	3.195	0.39	0.697
Eco. Progress (ECP^2)	1.053	0.312	3.37	0.001
Tech. Advancement (TAD)	0.615	0.455	1.35	0.177
Tech. Innovation (TA1)	0.382	0.411	0.93	0.353
Exp. Research and Dev. (R&D)	2.393	11.051	0.22	0.829
Urbanization (URB)	−0.632	0.460	−1.37	0.170
Constant	0.390	1.296	0.30	0.763
Country 3: Indonesia				
Carbon emissions (ENP)	−0.227	0.109	−2.09	0.037
Eco. Progress (ECP)	−12.912	1.517	−8.51	0.000
Eco. Progress (ECP^2)	−0.798	0.412	−1.93	0.053
Tech. Advancement (TAD)	0.420	0.304	1.38	0.167
Tech. Innovation (TA1)	−0.875	0.591	−1.48	0.139
Exp. Research and Dev. (R&D)	−2.737	1.772	−1.54	0.122
Urbanization (URB)	0.343	0.338	1.02	0.310
Constant	−0.568	0.588	−0.97	0.334
Country 4: Malaysia				
Carbon emissions (ENP)	−1.120	0.144	−7.76	0.000
Eco. Progress (ECP)	−0.476	0.477	−1.00	0.319
Eco. Progress (ECP^2)	4.794	1.236	3.88	0.000
Tech. Advancement (TAD)	0.795	0.304	2.61	0.009
Tech. Innovation (TA1)	−10.701	5.081	−2.11	0.035
Exp. Research and Dev. (R&D)	2.050	1.009	2.03	0.042
Urbanization (URB)	0.380	0.350	1.09	0.278
Constant	−4.102	3.739	−1.10	0.273
Country 5: Mongolia				
Carbon emissions (ENP)	−0.781	0.190	−4.11	0.000
Eco. Progress (ECP)	3.312	4.260	0.78	0.437
Eco. Progress (ECP^2)	0.264	0.461	0.57	0.567
Tech. Advancement (TAD)	0.008	0.079	0.11	0.912
Tech. Innovation (TA1)	0.254	0.147	1.73	0.083
Exp. Research and Dev. (R&D)	--	--	--	--
Urbanization (URB)	1.715	1.186	1.44	0.148
Constant	−1.870	2.579	−0.73	0.468
Country 6: Myanmar				
Carbon emissions (ENP)	−0.087	0.117	−0.75	0.455

Table 11 (continued)

Dependent variable: D.ENP				
Independent variables	Coef.	Std. Err.	z-stat.	*p* value
Exp. Research and Dev. (R&D)	2.440	1.251	1.95	0.051
Urbanization (URB)	−0.104	0.137	−0.76	0.448
Constant	−7.358	3.294	−2.23	0.026
Country 17: Kyrgyz Republic				
Carbon emissions (ENP)	−1.152	0.172	−6.67	0.000
Eco. Progress (ECP)	164.803	109.663	1.50	0.133
Eco. Progress (ECP^2)	0.161	0.243	0.66	0.508
Tech. Advancement (TAD)	−0.074	0.159	−0.47	0.639
Tech. Innovation (TA1)	0.618	0.456	1.36	0.175
Exp. Research and Dev. (R&D)	29.246	33.871	0.86	0.388
Urbanization (URB)	−3.188	3.305	−0.96	0.335
Constant	−2.436	2.634	−0.92	0.355
Country 18: Tajikistan				
Carbon emissions (ENP)	−0.330	0.110	−2.99	0.003
Eco. Progress (ECP)	−64.965	82.023	−0.79	0.428
Eco. Progress (ECP^2)	0.128	0.157	0.82	0.415
Tech. Advancement (TAD)	0.196	0.207	0.95	0.344
Tech. Innovation (TA1)	0.218	1.767	0.12	0.901
Exp. Research and Dev. (R&D)	8.803	14.223	0.62	0.536
Urbanization (URB)	−15.404	8.858	−1.74	0.082
Constant	1.082	0.904	1.20	0.232
Country 19: Uzbekistan				
Carbon emissions (ENP)	−0.402	0.085	−4.72	0.000
Eco. Progress (ECP)	−668.923	300.834	−2.22	0.026
Eco. Progress (ECP^2)	0.493	0.714	0.69	0.490
Tech. Advancement (TAD)	0.117	0.201	0.58	0.559
Tech. Innovation (TA1)	−0.033	0.194	−0.17	0.861
Exp. Research and Dev. (R&D)	−0.041	0.049	−0.84	0.401
Urbanization (URB)	−0.216	0.176	−1.22	0.221
Constant	−0.984	1.327	−0.74	0.458
Country 20: Egypt, Arab Rep				
Carbon emissions (ENP)	−0.108	0.125	−0.87	0.385
Eco. Progress (ECP)	−0.104	3.376	−0.03	0.975
Eco. Progress (ECP^2)	−0.038	0.314	−0.12	0.904
Tech. Advancement (TAD)	0.646	0.168	3.84	0.000
Tech. Innovation (TA1)	2.206	1.482	1.49	0.137
Exp. Research and Dev. (R&D)	−2.195	0.641	−3.42	0.001
Urbanization (URB)	0.160	0.102	1.56	0.118
Constant	−0.631	0.801	−0.79	0.430
Country 21: Iran, Islamic Rep				
Carbon emissions (ENP)	−1.130	0.250	−4.52	0.000
Eco. Progress (ECP)	−45.370	64.688	−0.70	0.483
Eco. Progress (ECP^2)	−3.830	3.870	−0.99	0.322
Tech. Advancement (TAD)	0.173	1.356	0.13	0.898
Tech. Innovation (TA1)	2.617	3.220	0.81	0.416
Exp. Research and Dev. (R&D)	−7.525	1.914	−3.93	0.000
Urbanization (URB)	0.090	0.161	0.56	0.577

Table 11 (continued)

Dependent variable: D.ENP				
Independent variables	Coef.	Std. Err.	z-stat.	*p* value
Tech. Advancement (TAD)	1.221	0.245	4.97	0.000
Tech. Innovation (TA1)	−27.074	10.780	−2.51	0.012
Exp. Research and Dev. (R&D)	--	--	--	--
Urbanization (URB)	--	--	--	--
Constant	4.522	1.330	3.40	0.001
Country 12: India				
Carbon emissions (ENP)	−0.608	0.262	−2.32	0.020
Eco. Progress (ECP)	2.065	7.325	0.28	0.778
Eco. Progress (ECP^2)	0.413	0.630	0.66	0.512
Tech. Advancement (TAD)	−1.543	0.628	−2.45	0.014
Tech. Innovation (TA1)	1.090	1.255	0.87	0.385
Exp. Research and Dev. (R&D)	4.183	12.024	0.35	0.728
Urbanization (URB)	−2.328	1.495	−1.56	0.119
Constant	0.437	1.459	0.30	0.764
Country 13: Nepal				
Carbon emissions (ENP)	−1.014	0.225	−4.50	0.000
Eco. Progress (ECP)	−3.136	1.383	−2.27	0.023
Eco. Progress (ECP^2)	0.379	0.235	1.61	0.106
Tech. Advancement (TAD)	0.537	1.445	0.37	0.710
Tech. Innovation (TA1)	--	--	--	--
Exp. Research and Dev. (R&D)	--	--	--	--
Urbanization (URB)	--	--	--	--
Constant	3.677	1.044	3.52	0.000
Country 14: Pakistan				
Carbon emissions (ENP)	−0.942	0.210	−4.47	0.000
Eco. Progress (ECP)	−17.387	6.560	−2.65	0.008
Eco. Progress (ECP^2)	0.613	0.287	2.13	0.033
Tech. Advancement (TAD)	1.393	0.597	2.33	0.020
Tech. Innovation (TA1)	18.108	17.407	1.04	0.298
Exp. Research and Dev. (R&D)	0.831	1.057	0.79	0.432
Urbanization (URB)	−2.126	1.233	−1.72	0.085
Constant	−0.997	1.835	−0.54	0.587
Country 15: Sri Lanka				
Carbon emissions (ENP)	−0.831	0.219	−3.79	0.000
Eco. Progress (ECP)	1.392	13.599	0.10	0.918
Eco. Progress (ECP^2)	−0.027	0.219	−0.13	0.900
Tech. Advancement (TAD)	0.892	0.804	1.11	0.267
Tech. Innovation (TA1)	−18.888	95.497	−0.20	0.843
Exp. Research and Dev. (R&D)	--	--	--	--
Urbanization (URB)	--	--	--	--
Constant	1.541	1.393	1.11	0.269
Country 16: Kazakhstan				
Carbon emissions (ENP)	−0.819	0.162	−5.04	0.000
Eco. Progress (ECP)	65.107	63.469	1.03	0.305
Eco. Progress (ECP^2)	4.850	2.971	1.63	0.103
Tech. Advancement (TAD)	−0.254	0.148	−1.72	0.086
Tech. Innovation (TA1)	2.180	0.699	3.12	0.002

Table 11 (continued)

Dependent variable: D.ENP				
Independent variables	Coef.	Std. Err.	z-stat.	*p* value
Constant	−12.888	5.206	−2.48	0.013
Country 22: Jordan				
Carbon emissions (ENP)	−0.510	0.167	−3.05	0.002
Eco. Progress (ECP)	−43.805	36.142	−1.21	0.226
Eco. Progress (ECP^2)	0.854	0.512	1.67	0.096
Tech. Advancement (TAD)	0.016	0.079	0.20	0.839
Tech. Innovation (TA1)	0.370	0.197	1.87	0.061
Exp. Research and Dev. (R&D)	31.242	27.325	1.14	0.253
Urbanization (URB)	−664.301	422.168	−1.57	0.116
Constant	−2.268	1.759	−1.29	0.197
Country 23: Lebanon				
Carbon emissions (ENP)	−0.660	0.202	−3.26	0.001
Eco. Progress (ECP)	489.634	368.717	1.33	0.184
Eco. Progress (ECP^2)	−0.405	0.656	−0.62	0.536
Tech. Advancement (TAD)	−0.034	0.260	−0.13	0.894
Tech. Innovation (TA1)	--	--	--	--
Exp. Research and Dev. (R&D)	--	--	--	--
Urbanization (URB)	--	--	--	--
Constant	−2.972	2.314	−1.28	0.199
Country 24: Turkey				
Carbon emissions (ENP)	−0.695	0.217	−3.19	0.001
Eco. Progress (ECP)	−175.690	63.878	−2.75	0.006
Eco. Progress (ECP^2)	−0.901	0.870	−1.04	0.300
Tech. Advancement (TAD)	0.781	1.392	0.56	0.575
Tech. Innovation (TA1)	42.751	22.981	1.86	0.063
Exp. Research and Dev. (R&D)	−484.601	361.829	−1.34	0.180
Urbanization (URB)	87.699	40.643	2.16	0.031
Constant	−2.290	2.148	−1.07	0.286
Country 25: Yemen, Rep				
Carbon emissions (ENP)	−0.860	0.242	−3.54	0.000
Eco. Progress (ECP)	−12.783	79.047	−0.16	0.872
Eco. Progress (ECP^2)	−13.370	8.486	−1.58	0.115
Tech. Advancement (TAD)	−0.162	0.417	−0.39	0.696
Tech. Innovation (TA1)	--	--	--	--
Exp. Research and Dev. (R&D)	0.340	1.751	0.19	0.846
Urbanization (URB)	−0.026	0.208	−0.13	0.898
Constant	−11.945	4.989	−2.39	0.017

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