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Does Technological Innovation Reduce Environmental Degradation? Evidence from China

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Developed and developing countries are trying to achieve sustainable growth in the present era. Unfortunately, despite being the world's largest developing country, China is among those countries that have a high ecological footprint as it emits 27 % of global carbon emissions in 2021. However, the encouraging fact is that China has become an emerging economy due to technological advancement. Many existing studies have suggested that technological innovation can overcome environmental degradation. Therefore, this study examines whether technological innovation has reduced environmental degradation in China from 1985 to 2018. This study uses the ecological footprint to measure environmental degradation in China. Furthermore, this study also explores the role of economic growth, trade openness, and population on environment. To estimate the models, ARDL cointegration technique is applied, and the findings are further validated using CCR, DOLS, FMOLS, and Granger causality techniques. Overall, empirical results indicate that technological advancement negatively impacts China's short- and long-term ecological footprint. This is understandable because more innovation leads to better technology that consumes fewer resources and has lower ecological footprints. However, environmental degradation is exacerbated by economic growth and population growth, whereas trade openness helps to mitigate environmental degradation in China. The diagnostic analysis of the study confirms the absence of heteroscedasticity, multicollinearity, and model instability. The study recommends using eco-friendly technologies that can reduce the usage of harmful alternative energy sources. Furthermore, carbon emissions need to be taxed, and environment friendly technologies need to be supported to promote long-term economic growth.

Keywords: *Ecological Footprint; Technological Innovation; Environmental degradation; ARDL; China.*

Introduction

There has been much discussion on climate change and global warming, which points to an environmental catastrophe due to the significant environmental consequences of economic policies in recent years (Zhang *et al.,* 2023). Concerning the productive capacity of the planet, the ecological footprint measures how quickly environment can absorb waste produced as a result of human activities by consuming natural resources and generating new resources (Ahmed, Zafar *et al.,* 2020). Economies worldwide are battling an ecological deficit that might result in climatic alteration, resource exhaustion, and ecological catastrophe. Moreover, various challenges, such as growing energy demand, expanding garbage creation, water crisis, and escalating ecological footprint are causing environmental degradation worldwide. The constant rise in the environmental footprint of countries has made achieving sustainable development exceedingly challenging (Ahmed, Asghar *et al.,* 2020; Jalil & Feridun, 2011; Porrini, 2017; Wang *et al.,* 2019; Yuan *et al.,* 2022). Unfortunately, despite being the world's largest developing country, China is among those countries that have a high ecological footprint, as shown in Figure 1. Because China is the world's largest coal producer and user (Jun *et al.,* 2020). Therefore, China's CO_2 emissions increase every year. As a result, in 2021, China was responsible for 27 % of global carbon emissions.

In recent years, the gap between China's energy supply and demand has grown, and the environment is getting worse, which is very bad for the Chinese economy and its long-term health (Hao *et al.,* 2016). In order to resolve this significant problem, technological innovation can play a major role and lead towards a low-carbon economy (Taylor *et al.,* 2005). Innovation also promotes productivity and economic growth and supports sustainable growth by effectively using natural resources (He *et al.,* 2021). As a consequence, China will be able to use technological innovation to meet the demands of a rising population and preserve the quality of the environment. Regarding this, switching from conventional technologies to greener ones, such as reprocessing, recycling, using cutting-edge procedures, and employing items that do not rely on natural resources, can promote economic growth while halting environmental damage (Hou *et al.,* 2023).

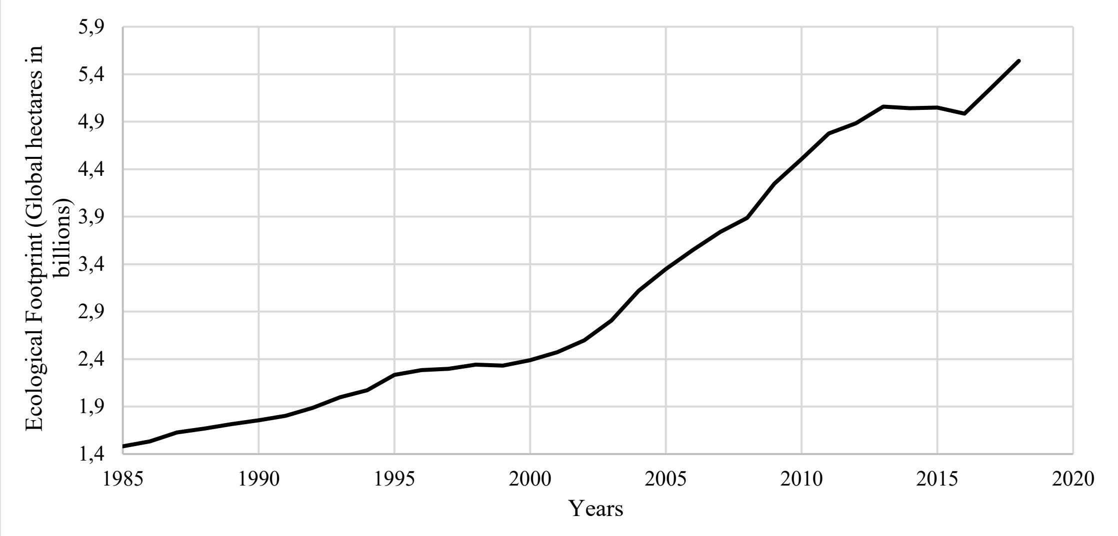

Figure 1. Ecological Footprint in China (1985–2018**)**

Since 1980s, China has been pursuing an open national agenda because it was at that time when it first began to open up and modernize. Then, in late 1990s, China emphasized indigenous innovation while maintaining a high level of openness to external knowledge. After this, the system became even more active in knowledge sourcing, employing nontraditional routes which are rarely employed in developing countries, such as foreign direct investment (FDI), international innovation partnerships, and the recruitment of highly skilled migrants. With the expansion of globalization and the development of the technological capacities of Chinese enterprises, policy direction has grown even more open in encouraging domestic firms to obtain sophisticated external expertise by going global. Moreover, a diverse innovation strategy has increased technological innovation in China. During the past few years of fast economic growth, China has made a conscious effort to go from being a technological backward to a dynamic and autonomous innovator. The route taken by China towards domestic innovation is marked by a constant stream of new scientific and technological projects developed by the government. China's transformation from a low-income to a high-income country has benefited from the enormous increase in technical potential. In order to achieve sustainable growth, China needs to reduce pollution and make essential changes before it is too late.

Considering the above arguments, the goal of this study is to find out how technological progress affects the China's environment which is getting worse. As a measure of environmental damage, the ecological footprint is used to compare how different things affect the atmosphere and the environment as a whole. It is thought to be a better indicator of environmental degradation than other indicators because it looks at grain fields, fishing spots, forest terrain, developed land, and CO_2 emissions all at the same time (Ahmed, Zafar *et al.,* 2020; Lin *et al.,* 2016; Nathaniel *et al.,* 2019).Analyzing China is important because its economy is large and it has made more technological investments than other developing countries. Furthermore, China accounted for over 27 % of global carbon emissions in 2019. This exceeds the total global carbon emissions of the United States and other industrialized countries and continues to grow annually.

The paper significantly contributes to the corpus of knowledge in several ways. First, this paper incorporates technological innovation into the model. It is worth noting that there are limited research studies available on technological innovation and ecological footprint, and studies on the impact of technological innovation on CO_2 emissions have inconsistent results. Total patent applications are used in the study as a measure of technological innovation, allowing researchers to see how technological growth helps to overcome environmental degradation in China. Second, this research examines the impact of economic and demographic factors like economic growth, trade openness, and population on ecological footprint. Thirdly, the study employs the latest data available from 1985 to 2018. Autoregressive Distributed Lag (ARDL) co-integration technique is used to examine the existence of a long-run relationship among variables. The Fully-Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS), and Canonical Cointegrating Regression (CCR) estimation techniques are used for robustness checks. Lastly, this study will help to identify the causes of China's ecological deficit and the policy implications needed to overcome the environmental deterioration.

The rest of the paper is organized as follows. Section 2 summarizes the existing literature. Section 3 describes the data and methodology of the study. Section 4 explains the empirical findings of the study. The last section of the study presents the conclusions with policy implications.

Literature Review

In the past few years, the influence of technological innovation on environmental degradation has become a serious concern (Mosconi *et al.,* 2020; Porrini, 2017; Sannigrahi *et al.,* 2019; Sannigrahi *et al.,* 2020). Numerous researchers have used carbon emissions as a proxy to evaluate ecological footprints in time series data, panel data and cross-section data. However, recently, ecological footprint has been employed as a measure of environmental degradation in several research studies (Aşıcı & Acar, 2016; Charfeddine, 2017; Charfeddine & Mrabet, 2017; Chu, 2022; Danish & Wang, 2019; Mrabet & Alsamara, 2017; Rafindadi & Usman, 2019; Shahbaz *et al.,* 2017; Uddin *et al.,* 2017). These studies examined the relationship between ecological footprint and economic growth in different countries. These studies have found that economic expansion has positively impacted the ecological footprint, implying that economic growth increases environmental degradation. However, here the main disquiet is China's ecological footprint.

China is the most important developing country because it is the world's second-largest economy and emits carbon dioxide (Yin et al., 2015). According to (Wang *et al.,* 2018), the integrity of the natural environment in eastern and central China is much below the national average. From 1978 to 2013, the level of ecological security went up, which means that China's ecological situation is quite dangerous. In this way, (Jalil & Mahmud, 2009) have found that rising income per person in China is directly linked to rising CO_2 emissions per person. However, (Jalil & Feridun, 2011) have shown that CO_2 emissions are influenced by development, energy use, and trade openness in China. (Alam et al., 2016; Govindaraju & Tang, 2013) have used time series data in a similar work. They have discovered a long-run association between CO_2 emissions, coal use, and growth in China. However, (Li & Hsu, 2016; Wang *et al.,* 2011; Wang *et al.,* 2016), using panel data from Chinese provinces, have found that increase in per capita income is responsible for increase in per capita CO_2 emissions. These studies also revealed that China's ecological footprint is badly affected due to the excessive carbon emissions. Thus, it is important to investigate it.

A new pattern of environment friendly manufacturing technology is emerging globally. According to World Intellectual Property Organization (WIPO), the number of patent applications for technological improvements in developing countries has increased from 0.11 million in 1980 to 1.74 million in 2016. In addition, (Song et al., 2019) have claimed that technical advancements could contribute to long-term sustainable growth by optimizing the use of natural resources, provided they are given proper attention. Moreover, technical innovation can help the world's economies overcome the shortage of precious natural resources and meet the requirements of an ever-increasing population while preserving the quality of the environment. Therefore, switching from conventional technologies to greener ones, such as reprocessing, recycling, and employing things that do not rely on natural resources, can promote economic growth while halting environmental damage. However, it happens only in developed countries (Bekun *et al.,* 2019). In this respect, ecologically friendly technological innovation can ensure the fulfillment of sustainable development.

The Chinese economy is growing quickly, which means that more energy is being used, which increases CO_2 emissions. Also, China, which has 18.47 % of the world's population, makes a big difference in the way the environment is getting worse. (Yin *et al.,* 2015) have documented that the only way to get on a path of sustainable growth is to stop the environment damage. (Sun *et al.,* 2008) have shown that technological advancements slow environmental degradation in China using environmental patents and cluster analysis. (Hang & Yuan-Sheng, 2011) have discovered the influence of technological progress on CO_2 emissions in China from 1980 to 2006 and this influence is found to be positive in the early stages but harmful in the later stages. Owing to absence of spending on research and development (R&D), technological improvements may impair environmental quality, preventing the ideal level from being achieved (Cheng *et al.,* 2019; Gu & Wang, 2018; Kivyiro & Arminen, 2014; Reid *et al.,* 2019; Yongping, 2011). However, by employing ARDL and VAR models and using data from 1971 to 2014, (Zhang, 2021) has found that energy and technological innovation, particularly in China's metropolitan areas, are critical for lowering environmental deterioration (Chu, 2022) has conducted a study and looked at how the ecological footprints of 20 OECD countries were affected by environmental technology. It has been found that the ecological footprint is not significantly affected by technological advancement. Therefore, the only goal of technical development is to enhance air quality. This makes sense since more innovation results in better technology that uses fewer resources. Using fewer resources will likely result in lower ecological footprint levels. Furthermore, scientific progress is essential for creating eco-friendly innovations that reduce the usage of unclean energy sources. Furthermore, (Xu *et al.,* 2022) have examined the relationship between technological innovation and natural resources in China from 1990 to 2017. Their findings suggest that technological innovation can help improve natural resource allocation.

To be brief, it is found that there is a need for more empirical analysis to gauge the impact of technological innovation on the ecological footprint in China, using some economic and demographic factors like economic growth, trade openness, and population. Moreover, most existing studies have focused on cross-country and panel data analysis. This study will use time series analysis to investigate the factors which are responsible for environmental degradation in China. In this regard, this study will fill this gap by exploring the role of technological innovation factors responsible for environmental degradation in China.

Data and Methodology

This paper uses annual time series data for China from 1985 to 2018. The time frame of the study is based on the availability of data for ecological footprint. The World Bank's database is used to collect data for technological innovation, economic growth, trade openness, and population. The data for the ecological footprint is collected from the Global Footprint Network (GFN). This study uses ecological footprint per capita (global hectare) to measure environmental degradation. Table 1 lists the variables used in this study along with their descriptions. In order to investigate the effect of technological innovation on the ecological footprint, the following model will be estimated:

Table 1

Variable Measurement

Variable	Measurement used	Source of Data
Ecological Footprint (EF)	Ecological footprint (Global hectares)	GFN
Technological Innovation (TIN)	Patent applications (resident + non-resident)	WDI
Economic Growth (EG)	GDP per capita (constant 2010 US dollars)	WDI
Trade Openness (TO)	Trade (% of GDP)	WDI
Population (POP)	Population growth (annual %)	WDI

$$EF_t = \beta_0 + \beta_1 TIN_t + \beta_2 EG_t + \beta_3 TO_t + \beta_4 POP_t + \varepsilon_t \quad (1)$$

The ecological footprint is denoted as EF, TIN stands for technological innovation, economic growth is abbreviated as EG , TO stands for trade openness, POP refers to population and ε_t is error term. After taking natural logarithm the above model can be written as:

$$lnEF_t = \beta_0 + \beta_1 lnTIN_t + \beta_2 lnEG_t + \beta_3 lnTO_t + \beta_4 lnPOP_t + \varepsilon_t \quad (2)$$

Econometric Methodology

In this study, advanced econometric techniques are used to find out the effects of technological change on ecological footprint. The Augmented Dickey-Fuller test (ADF) proposed by (Dickey & Fuller, 1981), the Phillips-Perron test (PP) proposed by (Phillips & Perron, 1988), and the DF-GLS unit root test proposed by (Elliott et al., 1992) are used for stationarity analysis. The Autoregressive Distributed Lag (ARDL) cointegration approach suggested by (Pesaran et al., 2001) is then used to ascertain the cointegration among the variables. Finally, the long-run coefficients are estimated using estimation techniques of Dynamic Ordinary Least Squares (DOLS) by (Stock & Watson, 1993), Fully-Modified Ordinary Least Squares (FMOLS) by (Phillips & Hansen, 1990), and Canonical Cointegrating Regression (CCR) by (Park, 1992). The DOLS model provides an asymptotically efficient estimator that does not have to worry about simultaneity, endogeneity, or autocorrelation. In addition, the FMOLS has the benefit of accounting for endogeneity problems, producing reliable checks of robustness results for small samples. According to (Bildirici, 2017), the CCR is an easy-to-use cointegrating regression model founded on the variables' transition.

The ARDL methodology is an exceptionally versatile approach as it allows mixed orders of integration, i.e. I(0) and I(1) (Pesaran *et al.,* 2001). Additionally, this approach may adjust the lag order to prevent endogeneity and residual serial correlation (Shahbaz *et al.,* 2015). Our model in ARDL form is written as follows:

$$\Delta lnEF_t = \delta_0 + \sum_{k=1}^{q} \delta_{1k} \Delta lnEF_{t-k} + \sum_{k=0}^{p} \delta_{2k} \Delta lnTIN_{t-k} + \sum_{k=0}^{p} \delta_{3k} \Delta lnEG_{t-k} + \sum_{k=0}^{p} \delta_{4k} \Delta lnTO_{t-k} + \sum_{k=0}^{p} \delta_{5k} \Delta lnPOP_{t-k} + \beta_1 lnEF_{t-1} + \beta_2 lnTIN_{t-1} + \beta_3 lnEG_{t-1} + \beta_4 lnTO_{t-1} + \beta_5 lnPOP_{t-1} + \varepsilon_t \quad (3)$$

In the above equation, the lag length is indicated by p, and the first difference operator is denoted by Δ. The short-run analysis equation is given below:

$$\Delta lnEF_t = \omega ECT_{t-1} + \sum_{k=1}^{q} \delta_{1k} \Delta lnEF_{t-k} + \sum_{k=0}^{p} \delta_{2k} \Delta lnTIN_{t-k} + \sum_{k=0}^{p} \delta_{3k} \Delta lnEG_{t-k} + \sum_{k=0}^{p} \delta_{4k} \Delta lnTO_{t-k} + \sum_{k=0}^{p} \delta_{5k} \Delta lnPOP_{t-k} \quad (4)$$

The short-run relationship is denoted by the coefficient δ, whereas the long-run relationship is denoted by the coefficient β.

Empirical Results

First, the descriptive statistics of the study are presented in Table 2. The mean value of ecological footprint is 21.77, with a minimum value of 21.11 in 1985 and a maximum of 22.43 in 2018, which indicates significant environmental degradation in China. Technological innovation has a minimum value of 8.988 and a maximum value of 14.24, indicating that technology utilization in China was lower in 1985, which has increased in recent years. The minimum and maximum values of economic growth are 5.528 and 9.200 between 1985 and 2018, respectively. It shows economic expansion in China overtime. The minimum and maximum values of trade openness are 2.951 and 4.166 in 1985 and 2018 respectively. It shows that China's trade has expanded overtime. The minimum and maximum values of population are 0.759 and 1.476, respectively, showing a drastic increase in the population from 1985 to 2018.

Table 2

Descriptive Statistics

Variables	N	Mean	Median	Min	Max	Std. Dev.
EF	34	21.77	20.85	21.11	22.43	0.429
TIN	34	11.36	11.06	8.988	14.24	1.786
EG	34	7.223	9.399	5.528	9.200	1.241
TO	34	3.600	3.626	2.951	4.166	0.359
POP	34	0.200	0.726	0.759	1.476	0.408

Table 3 displays the stationarity analysis of the variables used in the study. All the unit root tests, including the ADF, PP, and DF-GLS tests, show similar findings. Except for economic growth, every variable is stationary at the first difference, I(1). We have mixed results regarding the stationarity of the variables.

Table 3

Unit Root Test Results

Variables	DF-GLS Test		ADF Test		PP Test		Outcome
	Level	1st Diff	Level	1st Diff	Level	1st Diff	
$lnEF$	-1.907	-3.747**	-1.140	-3.110**	-1.840	-3.193**	I(1)
$lnTIN$	-1.958	-7.513**	-2.917	-5.563**	-1.050	-5.641**	I(1)
$lnEG$	-6.014**	-	-3.372**	-	-1.773	-3.282**	I(0)
$lnTO$	-1.444	-4.523**	-1.630	-5.445**	-1.637	-5.481**	I(1)
$lnPOP$	-1.652	-3.195**	-2.403	-3.131**	-0.541	-3.920**	I(1)

*Note: ** indicates that* $p < 0.05$

Zivot-Andrews (1992) unit root test is also used, as it is more reliable because it also considers structural break in the data. Table 4 shows the results of the Zivot-Andrews unit root test. All variables except economic growth are integrated of order one i.e. at I(1) with a structural break, while economic growth is integrated of orecr zero i.e. I(0). Ecological footprint has experienced a structural break in 2003 due to numerous climatic catastrophes. The Ministry of Ecology and Environment China claims that scorching weather struck China's southeast and south in the summer. The disasters caused by typhoons and sandstorms were less severe than in the years prior, but those caused by droughts, storms, floods, heat waves, extended periods of rainy weather, and hail were more severe (Wen, Khalid, et al., 2021; Wen, Mahmood, et al., 2021). As a result, China's ecological deficit began and steadily expanded over time. Technological innovation observed a structural break in 1998 due to the Sino-US relationship crisis. According to a United Nations report, this was the time of China's technological revolution, and China was the tenth-largest high-tech exporting country in the world from 1998 to 1999.The unit root findings allow us to move forward with the ARDL bounds test for co-integration analysis since we have a mixed order of integration.

Table 4

Zivot-Andrews (Structural Break) Unit Root Test

Variables	Level		1st Diff	
	t-stat	Break Year	t-stat	Break Year
$lnEF$	-2.913	1996	-4.415**	2003
$lnTIN$	-4.114	2003	-6.444**	1998
$lnEG$	-4.911**	2007	-	-
$lnTO$	-2.104	2009	-7.012**	2007
$lnPOP$	-3.390	2008	6.083**	2011

*Note: ** indicates that* $p < 0.05$

Now it is crucial to choose the best lag length for co-integration and causality analysis after discovering the stationarity of the variables. Table 5 shows the optimal lag length selection criterion. As per Akaike information criterion (AIC), Schwarz information criterion (SIC), and Hannan-Quinn (HQ), lag length selection criterion, the optimal lag length is 2.

Table 5

Optimal Lag Length Selection

Lag	AIC	SIC	HQ
0	11.33	11.60	11.42
1	1.932	3.875	2.565
2	-0.102*	3.505*	1.073*

*Note: Optimal lag length is represented by the **

The results of the ARDL-bound test are shown in Table 6. The F-statistic is 7.705, more than the upper and lower bound crucial values at the 5 % significance level. The null hypothesis of no cointegration is thus rejected at different levels of significance, implying that the variables are cointegrated. This suggests that there is long-term between the variables. We can proceed to the next step and estimate the long- and short-run relationships using the ARDL cointegration model.

Table 6

Bound Test for Co-Integration

F-statistic	7.705** [0.03]	
Critical Values (at 5% level)	**Upper Bound I(1)**	**Lower Bound I(0)**
	4.68	2.62

Note: ** indicates that $p < 0.05$. Values in [] are p values.

Table 7 depicts the long-term relationship between all the variables and their ecological footprint. In the long run, there is a negative impact of technological innovation on ecological footprint, which shows that a 1 % increase in innovation reduces ecological footprint by -0.276 %. The negative association between technical breakthroughs and the ecological footprint is reasonable, assuming that technological innovations are vital to estimate and impose for China's long-term growth. Moreover, technological developments assist in the reduction of CO_2 emissions with the improvement of energy efficiency, leading to lower ecological footprint. The findings of (Mensah *et al.,* 2018) for the OECD and (Shahbaz *et al.,* 2019) for China have shown that technological advancements have moderating effect of ecological footprint. This result also coincides with investigations by (Ahmed *et al.,* 2016) and (Ibrahiem, 2020). This result supports the notion that only environment friendly technological innovation can ensure sustainable development (Chu, 2022). Because more innovation results in better technology that uses fewer resources, using fewer resources will likely result in lower levels of ecological footprint. Furthermore, scientific progress is essential for creating eco-friendly innovations that reduce the usage of unclean energy sources. This reasoning, however, runs counter to the study of (Santra, 2017), which has indicated that technological breakthroughs cause the carbon footprints of the BRICS countries to grow. Economic growth positively affects the ecological footprint indicating that China's ecological footprint increased by 0.721 % for every 1 % increase in economic growth. This finding is consistent with the findings of (Ahmed, Zafar *et al.,* 2020) which also indicates the harmful effects of economic expansion on ecological footprint. Studies by (Danish & Wang, 2019) and (Uddin *et al.,* 2017) support the positive effect of economic growth on ecological footprint. Given that China's economy is now expanding at the fastest rate in the world and that its income has dramatically expanded over the past 40 years, the harmful effects of economic growth on ecological footprint seem inevitable. Every area of the economy has seen increased resource consumption as income has increased. China now consumes more energy than any other country and has the most significant overall environmental impact (Mahmood *et al.,* 2022).

Trade openness has negative impact on ecological footprint, as the estimated results show that 1 % increase in trade openness reduces the ecological footprint of China by -0.767 %. The significantly negative coefficient of trade openness suggests various factors, including the introduction of technology and equipment in China in recent years due to trade openness. The rapid expansion of industrial competition and the resulting upgrade in the industrial structure are all favorable to human capital accumulation. Increasing trade openness boosts the output of goods and services, boosts demand for technology, and improves environmental quality, as supported by previous studies ((Alhassan *et al.,* 2020; Antweiler *et al.,* 2001; Cole & Neumayer, 2004).

Table 7

ARDL Test Results

Dependent Variable: $LnEF$		
Variable	**Co-efficient**	**Std. Error**
Long run Analysis		
$lnTIN$	-0.276***	0.094
$lnEG$	0.721***	0.151
$lnTO$	-0.767**	0.301
$lnPOP$	0.524**	0.261
Short run Analysis		
C	21.13***	6.038
$\Delta lnTIN$	-0.086**	0.037
$\Delta lnEG$	0.644***	0.168
$\Delta lnTO$	-0.252***	0.088
$\Delta lnPOP$	0.450***	0.117
ECT	-0.978***	0.317

Note: *** indicates that $p < 0.01$ and ** indicates that $p < 0.05$

Finally, population positively impacts the ecological footprint indicating that China's ecological footprint grows by 0.524 % with every 1 % increase in the population. The positive impact of population on ecological footprint is also supported by some notable studies (Cole & Elliott, 2003; Dietz & Rosa, 1997; Khan *et al.,* 2021; Liddle & Lung, 2010; Martínez-Zarzoso *et al.,* 2007; Shi, 2003; Udemba, 2020). As we already know, China's population covers 18.47 % of the world's population. This growing population of China deteriorates the environmental quality. All the estimated coefficients are statistically significant.

Table 7 also shows the short-run analysis. The short-run results are similar to the long-run results of the study. The coefficient of error correction term (ECT) is -0.978 and is significant at 1 % significance level. This suggests the adjustment of short-term disequilibrium in the long run.

Robustness Check

The CCR, DOLS, and FMOLS are used for robustness analysis. Table 8 presents the estimated results of this robustness analysis. As is evident from the results, the coefficient of technology is negative in the long-term estimates for all these models. This estimated result suggest that technological innovation negatively and significantly influences the ecological footprint. These results show that technological progress aids in slowing environmental damage. Values of estimated coefficient show that 1% increase in technological innovation results in a 0.081%, 0.280% and 0.081% decrease in ecological footprint in CCR, DOLS and FMOLS estimates, respectively. These findings show that China has the capability and motivation to develop environment friendly technological advancements. It has been found that technological innovation helps to lessen environmental footprints, suggesting that technological innovation in China is not only advantageous to the growth of domestic environmental sustainability but also helps to lessen environmental deterioration. This result supports the findings of (Xu et al., 2022). The coefficient of economic growth is positive and statistically significant at various levels of significance. The rise in income has boosted the consumption of resources across the board, which has adversely affected the environment. The coefficient of trade openness is negative and statistically significant. It implies that trade openness has improved environment by importing high technology goods in China. Finally, the coefficient of the population is positive and statistically significant, which indicates the detrimental effect of high population on environment in China. The results of robustness tests validate the findings of ARDL estimates.

Table 8

Robustness Test

Dependent Variable: $LnEF$			
Variables	**Model**		
	CCR	**DOLS**	**FMOLS**
C	0.559** [0.280]	0.042*** [0.014]	1.443** [0.596]
$LnTIN$	-0.081*** [0.023]	-0.280** [0.137]	-0.081** [0.034]
$LnEG$	0.241*** [0.028]	0.254*** [0.038]	0.121** [0.054]
$LnTO$	-0.049*** [0.005]	-0.083*** [0.027]	-0.684** [0.278]
$LnPOP$	0.233*** [0.071]	0.586** [0.239]	0.178*** [0.058]

*Note: *** indicates that* $p < 0.01$ *and ** indicates that* $p < 0.05$

The Granger causality test is used to determine whether there is a causal connection between the variables after looking at their long-term relationships. Vector autoregressive (VAR) framework is used to test Granger causality. Table 9 displays the Granger causality between the variables. The results show that there is a one-way causality from technological innovation, trade openness and population to ecological footprint. It supports the findings of

(Sabir & Gorus, 2019). In Turn, bidirectional causation exists between ecological footprint and economic growth, indicating that both economic expansion and ecological footprint cause each other. This result supports the findings of previous research findings (Kihombo *et al.,* 2021; Shahbaz & Leita, 2013; Shahbaz *et al.,* 2013). The findings of this study show that how choosing a certain pollution indicator like ecological footprint can alter causal relationships. Using ecological footprint analysis, environmental concerns other than carbon emissions can be addressed more thoroughly (Pata & Caglar, 2021).

Table 9

Granger Causality Test Results

Null Hypothesis	F Statistics	P value	Causality
$LnTIN$ does not Granger cause LEF $LnEF$ does not Granger cause $LNTIN$	7.790** 2.100	0.02 0.368	Yes
$LnEG$ does not Granger cause $LnEF$ $LnEF$ does not Granger cause $LnEG$	6.865** 7.616**	0.03 0.02	Yes
$LnTO$ does not Granger cause $LnEF$ $LnEF$ does not Granger cause $LnTO$	7.539** 2.096	0.02 0.351	Yes
$LnPOP$ does not Granger cause $LnEF$ $LnEF$ does not Granger cause $LnPOP$	11.71*** 1.996	0.00 0.369	Yes

*Note: *** indicates that* $p < 0.01$ *and*
*** indicates that* $p < 0.05$

Table 10 reports the diagnostic tests of the study. These tests include heteroscedasticity, multicollinearity, and model stability tests. All the diagnostic tests confirmed the absence of heteroscedasticity and multicollinearity problems.

Table 10

Diagnostic Test Results

Diagnostic Test	p-value
Multicollinearity Test	0.744
Heteroscedasticity Test	0.961
Ramsey RESET Test	0.428

Figure 2 shows the CUSUM squared graph, indicating the stability of parameters.

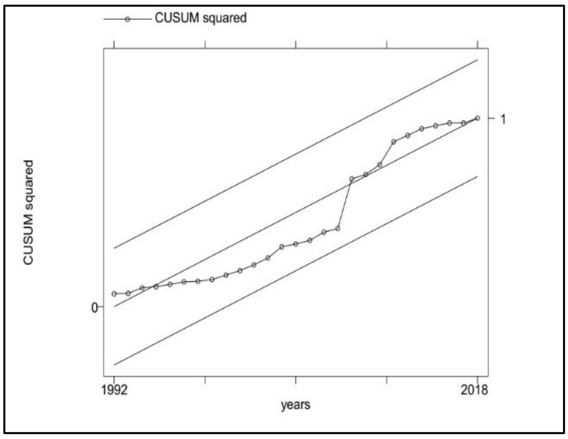

Figure 2. CUSUM Square Graph

Conclusions and Policy Implications

Conclusions

In the last few decades, China's economy has grown rapidly. This has led to more use of energy and natural resources. At the same time, China has a huge ecological deficit that could lead to terrible environmental problems like the loss of natural resources and ecological reserves. Therefore, the present study attempts to explore this issue due to the limited research in the case of China. This study examines the impact of technological innovation on environmental degradation in China from 1985 to 2018. The ecological footprint of China is shown to be significantly and negatively affected by technological advancement and trade openness. The reason is that the adaptation of green and clean trade, as well as technology, will negatively impact hazardous sectors, thereby improving China's environmental quality. However, economic growth and population have been found to affect environmental degradation positively.

Policy Implications

Based on the findings of this study, some policy implications are presented. China needs to invest more in innovation so that it can help lower energy intensity and aid in reducing carbon emission levels. Furthermore, the government should encourage enterprises and citizens of the country to install technology that helps reduce carbon intensity and improve environment. For this government can uses tax and other incentives.

Innovations in technology can be helpful if they are used in the right way to make the best use of natural resources. In this regard, cleaner and more environment friendly technologies may be used to achieve long-term growth. Moreover, projects that benefit the environment should receive careful consideration from the government. Since China's economic expansion is occurring at the expense of environmental damage, therefore, government should ensure that natural resources are utilized responsibly, such as coal and other natural fossil fuels. However, incorporating green and clean technologies into the damaging industries would improve the country's overall environment quality.

The results have shown that trade openness benefits environmental sustainability in China. Therefore, China should vigorously promote trade openness, upgrading technological and industrial structures, and accumulating human capital through trade openness.

Lastly, China's policies on trade, energy, and technological innovation will boost the country's overall economic growth. There is need to ensure that China's growth is balanced and stable. In line with this, the adaptation of green and clean trade and technology and energy policy will significantly impact hazardous sectors, thereby improving China's environmental quality. From a policy standpoint, no single or individual policy variable like trade or technology will provide a positive result. As a result, China's long-term growth needs to be ensured by an integrated macroeconomic strategy. The government must implement training and awareness programs to teach workers about the need for technological innovation and sustainable working and living habits, as well as how to prevent excessive carbon emissions. Policies to raise environmental awareness may enhance demand for green energy solutions and environment friendly technologies. The current energy efficiency programs cannot sufficiently mitigate the negative impacts of energy use. On the other hand, green energy policies will demand proper financial planning to pay the expenses and a careful assessment of the possible implications on economic growth.

Future Research Direction

Present study explores the connection between technological innovation and the ecological footprint of a single country like China. Future studies can examine this relationship at regional level so that environmental policies can be made for each region.

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