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Does Financial Development and Eco-Innovation Promote Environmental Sustainability? Evidence from China through Auto Regressive Distributed Lag Approach

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Abstract

Purpose: This study scrutinizes the dynamic effects of financial development (FIN-DEV) and eco-innovation (ECO-INO) on China's carbon dioxide emissions (CO2-EMS) from 1980 to 2020, addressing the increasing urgency to mitigate environmental damage through innovative solutions.

Design/methodology/approach: Using the World Bank Indicators as the data source, this research used ARDLtechnique to determine the long-run cointegrated association among variables. Additionally, an error correction model is used to investigate short-run dynamics.

Findings: The practical verdicts indicate a long-run cointegrated association among the variables, consistent with endogenous growth theory. FIN-DEV and ECO-INO significantly reduce CO2-EMS in the long run. Among the control variables, trade openness (TOP) also contributes to emission reduction, while industrialization and urbanization increase emissions.

Research limitations/implications: The study focuses on China, and results may vary in different regional contexts. Future research could explore similar dynamics in other countries to enhance the generalizability of the findings.

Practical implications: The findings revealed the importance of innovation in reducing carbon dioxide emissions. Governments and policymakers are encouraged to support eco-innovation initiatives to combat environmental degradation effectively.

Originality/value: This study underscores the importance of integrating financial development with eco-innovation to address environmental challenges. It provides valuable insights for scholars and policymakers on leveraging market mechanisms to accelerate eco-innovation and mitigate climate change.

Keywords: Carbon emissions, Eco-innovation, Error correction model, Industrialization

Classification: Research paper

Introduction

Energy is one of the most vital element for economic development and improving quality and standard of life (Chiu & Lee, 2020). Energy is used as an basic material in the production, consumption, and distribution of almost all goods and services, and it helps in fostering economic development (Mukhtarov et al., 2020; Sadorsky, 2010). According to the US Energy Information Administration (EIA, 2019), the need for world emergy is estimated to surge up to 50 percent (approximately) from 2018 to 2050. The world primary energy demand between 2005 and 2030 is anticipated to raise at an typical growth rate of 1.8 percent (IEA, 2007).

Energy mandate modeling is also essential in ahead a better considerate of the ways to achieve global emission of greenhouse gases (GHGs) as energy-related GHG emissions constitute the majority of GHG emissions. Fossil fuels cover most of the global energy demand (EIA, 2019). An upsurge in the use of various natural incomes including fossil fuels is causing environmental degradation (Mukhtarov et al., 2020). The usage of fossil fuels has expanded since the Industrial Revolution, which has led to an upsurge in the atmospheric concentration of GHGs--the main contributor to global warming. It is widely assumed that environmental difficulties brought on by global warming will be the primary cause of issues that will transcend beyond national boundaries (Yurdakul & Kazan, 2020). In this connection, renewable energy-related R&D is considered as one of the significant and essential tools for decreasing GHG emissions (Gu &Wang, 2018). The rank of renewable energy in the world's energy mixes over the last decades is increasing due to the sharp increase in energy consumption, and technology development. Therefore, a durable commitment to scale back climate pollution and increased policy support for eco-innovation is required over the long run (Anton & Nucu, 2020).

Financial development (FIN-DEV) is considered as one of the key determinants of the level of energy demand (Destek, 2018; Sadorsky, 2010). FIN-DEV is the improvement of financial markets, institutions, and tools to promote economic growth and increase resource allocation efficiency. It promotes general economic stability and development by promoting investment, releasing savings, and enhancing access to financial services, all of which propel economic growth.

FIN-DEV positively affects energy consumption as it influences carbon dioxide emissions (CO_2-EMS) by hastening energy efficiency through the adoption and promotion of the latest technologies, and technological innovations (Wang et al., 2020). Also, a mature financial system fetches numerous benefits to the renewable energy sector—e.g., it generates a lot of funding for the renewable energy firms at a low cost, pumps in more foreign direct investment (FDI), reduces financial risk and the cost of the loan, increases in stock market activity and banking activities (Anton & Nucu, 2020; Mukhtarov et al., 2020). Moreover, FIN-DEV has three main impacts energy consumption. The first impact is called as direct impact which indicates that financial development might facilitate customers to borrow money for getting expensive tickets and so on, transferal regarding an upsurge in energy consumption. Further, the second impact is called as the business impact, facilitating firms and businesses to get access to financial capital for investment purposes. Third, the wealth impact shows that a rise in stock market activities may upsurge consumer and business confidences, raise energy consumption, and encourage economic activities (Sadorsky, 2011).

Eco-innovation (ECO-INO) is defined as new ideas, products and processes that help in decreasing environmental degradation and the concept implies that the practices of the business are synchronized with the environmental prospects (Colin et al., 2012; Fussler & James, 1996; Kemp & Pearson, 2007; Rennings, 2000). ECO-INO is the creation and use of goods, procedures, or services that lessen their negative effects on the environment and encourage sustainable behavior. Through increasing productivity and promoting green technology, ECO-INO is essential for attaining sustainable development, lowering ecological footprints, and boosting economic competitiveness. ECO-INO has been observed as a key gauge in prompting a sound environmental strategy, improving environmental performance as well as operational efficiency and future sustainability (Aguilera & Ortiz, 2013; Fethi & Rahuma, 2020). ECO-INO taking place in the energy sector is giving rise to renewable energy production. According to Ji et al. (2020), ECO-INO reduces CO2-EMS. ECO-INO is taken into account as a solution for preventing environmental harm and is known to lessen air pollution, waste production, and material resource consumption (Yurdakul & Kazan, 2020; López-Gamero et al., 2010). As specified by Serrat (2009), the quality of products can be improved by the company if the companies adopt the concept of product innovation to scale back the value of production through process innovation. Eco-product innovation contributes to the decrease of environmental influences with the help of noteworthy development of new or extant products or services (Reid & Miedzinski, 2008). Instigating ECO-INO at the corporate level requires long term assurances in the form of expenditures for R&D, staff training, and investment in physical assets (Fernández et al., 2018). R&D investment is taken under consideration as an efficient method for improving environmental policies, which generally comprise the improvement of latest environmental-friendly technologies likewise more viable products and services and more efficient operational process (Lee & Min, 2015). Eco-process innovation needs a change in systems and processes by increasing investment in new technology and R&D (Cheng et al., 2014), reduces resource costs, increase productivity, and reduces greenhouse gas emissions (Fethi & Rahuma, 2020; Kemp & Arundel, 1998). Eco-organizational innovation refers to the responsibilities, corporate technique, and method design within the corporation to reduce environmental impacts.

From the discussion above, it can be said that FIN-DEV and ECO-INO both are oriented towards environmental degradation. FIN-DEV may support ECO-INO by giving businesses the money they need to invest in sustainable practices and green technologies, as well as by offering financial incentives. In turn, ECO-INO can aid in lowering CO2-EMS by encouraging the use of greener technology and energy efficiency. By effectively directing funds toward eco-friendly initiatives, a well-designed financial system facilitates this shift by lowering carbon emissions and fostering sustainable economic growth. The silent feature of FIN-DEV is their contribution to economic growth and development and along with that ECO-INO is perceived to be the main instrument in instigating a rigorous environmental strategy, improving environmental performance as well as operational efficiency and future sustainability and is taken into account as a solution for preventing environmental harm. These premises motivate us to analyze environmental degradation based on the factors derived from the aforementioned context. This research study specifically studied the impact of FIN-DEV and ECO-INO on CO2-EMS in China.

The rest of the paper is structured as follows: The second section of the paper gives a detailed review of the literature that focuses on the connections between FIN-DEV, ECO INO, and CO2-EMS in various economies. A description of the data and a model's specifications are provided in the third section. The fourth section expands on the current subject and examines the empirical findings. Conclusions are made in the final part.

Literature Review

Financial Development and Carbon Dioxide Emissions

Designing solutions that strike a balance between environmental sustainability and economic growth requires an understanding of the relationship between FIN-DEV and CO2-EMS. CO2-EMS emissions are influenced by FIN-DEV in two ways: on the one hand, it is defined by the growth and sophistication of financial markets, institutions, and instruments. On the one hand, it may stimulate the expansion of industry and raise energy use, which raises emissions. Conversely, it offers the required funds for investments in renewable energy and greener technology, which may eventually result in a decrease in emissions. Anton and Nucu (2020) determined the association between FIN-DEV and the use of renewable energy by employing a panel data set for the time period from 1990 to 2015. The results showed a positive association of FIN-DEV with renewable energy consumption. Similarly, Mukhtarov et al. (2020) examined the relationship between FIN-DEV, GDP, energy consumption, and energy prices in Kazakhstan. The study results disclose that there is a significant positive impact of GDP and FIN-DEV on energy consumption. Jalil and Feridun (2012) analyzed the association between FIN-DEV and CO2-EMS in China. The findings of the ARDL method suggested that FIN-DEV decrease CO2-EMS in China. Likewise, the outcome confirm the presence of an EKC hypoyhesis for the said economy. Cetin and Bakirtas (2020) examined the interactions between GDP, FIN-DEV, and CO2-EMS for fifteen developing economies from 1980–2014 by applying heterogeneous dynamic panel data techniques. The results for selected developing economies show that one percent increase in FIN-DEV increases CO2-EMS at 0.76 percent. Ozturk and Acaravci (2013) examined the influence of FIN-DEV, TOP, and GDP on CO2-EMS in Turkey by taking annual data from 1960-2007. The results show that there is association between FIN-DEV, GDP, and CO2-EMS. Bekhet and Othman (2017) investigated the role of FIN-DEV in CO2-EMS for Malaysian economy by using ARDL approach and indicated that FIN-DEV upsurges CO2-EMS. Pata (2019) used a similar approach for the Turkish economy and determined that FIN-DEV enhance CO2-EMS. Along with this, there is a significant relationship for FIN-DEV, TOP, with CO2-EMS (Shahbaz et al., 2013). For Kuwait, Salahuddin et al. (2018), found that FDI, GDP and FIN-DEV had a noteworthy and positive effect on CO2-EMS for the 1960-2007 period by employing ARDL approach.

More recently, Shahbaz et al., (2020) analyzed the link between FIN-DEV and environmental degradation in the UAE for the period 1975Q1 to 2014QIV. The findings show that FIN-DEV is positively related to CO2-EMS. Likewise, Sadorsky (2010) analyzed the nexus between FIN-DEV and CO2-EMS in a sample of 22 emerging countries. Panel data sets from 1990 to 2006 were employed in the study. The result of the study suggested the presence of a statistically significant positive association between FIN-DEV and CO2-EMS. Similarly, Destek (2018) examined the effects of FIN-DEV on CO2-EMS for the case of 17 emerging countries. The study uses three dimensions for FIN-DEV and the impact of each of the three dimensions has been investigated on CO2-EMS. Using annual data over the period 1991-2015, the study found that one of the dimension is more effective in reducing energy consumption. Saidi and Mbarek (2017) studied the role of urbanization, income, FIN-DEV, and TOP on CO2-EMS for the case of emerging economies. This study uses time series data for a period 1990 to 2013 and the results from GMM estimation revealed that FIN-DEV minimizes environmental degradation. Likewisen, Charfeddine and Kahia (2019) discovered a positive association between FIN-DEV and CO2-EMS. Numerous aspects, such as the degree of economic development, legal frameworks, and technology breakthroughs, influence this intricate relationship. Policymakers and financial organizations seeking to strike a balance between environmental preservation and economic growth must comprehend this relationship.

Eco-innovation and Carbon Dioxide Emissions

By encouraging the adoption of sustainable practices and green technologies, eco-innovation plays a critical role in lowering CO2-EMS and minimizing the effects of climate change. The creation and use of ecologically friendly technology and procedures, or "eco-innovation (ECO_INO)," has a big influence on cutting CO2-EMS. ECO-INO lessen the negative effects of industrial activity on the environment by encouraging energy efficiency, cutting waste, and making it easier to adopt renewable energy solutions. Higher ECO-INO levels are often correlated with lower CO2-EMS because they promote the shift to more environmentally friendly manufacturing and consumption methods, which in turn promote environmental sustainability. Fussler and James (1996) presented the idea of ECO-INO. There is evidence that ECO-INO is a successful strategy for solving environmental issues (Zhang et al., 2017). Fethi and Rahuma (2020) used Porter strategy in order to examine the dynamic effects of three ECO-INO indicators on CO2-EMS. The findings show that investment, one of the proxies for ECO-INO, dramatically lowers CO2-EMS, while education and research and development also significantly lower CO2-EMS respectively. Yurdakul and Kazan (2020) scrutinized the effects of ECO-INO on CO2-EMS emissions and financial performance in Turkey. According to the SEM findings, ECO-INO has a direct impact on resource conservation, recycling, and pollution reduction.

Lee and Min (2015) examined how ECO-INO affected financial and environmental performance. In the study, ECO-INO is represented by green R&D. The study discovered a negative correlation between R&D and CO2-EMS using annual data for Japanese industrial companies from 2001 to

2010. Zhang et al. (2017) examined into how ECO-INO affected CO2-EMD in China for the years 2000 to 2013. Findings show that ECO-INO significantly reduces CO2-EMS in China. For thirteen advanced countries, Garrone and Grilli (2010) found a correlation between R&D and CO2-EMS. For the Malaysian economy from 1971 to 2013, Yii and Geetha (2017) analyzed the association amid technical innovation and CO2-EMS. Granger causality test results and the ARDL technique revealed a short-term inverse association between technological innovation and CO2-EMS, but no such relationship was discovered over the long term. Yusuf et al. (2018) studied the long-term connotation between technological innovation and CO2-EMS in Indonesia using the Kuznets Curve approach. On the basis of data from 1980 to 2017, they used FMOLS and DOLS. Their empirical study revealed a significant inverse association between technological innovation and CO2-EMS in Indonesia over the long term. Using data from the Chinese provinces from 2000 to 2014, Wang et al. (2018) employed spatial econometric models and found that technical developments in the energy sector can be extremely important for lowering CO2-EMS in China. Fan and Hossain (2018) estimated the effect of technological advancements on CO2-EMS in China and India using data from the years 1974 to 2016. Their findings indicated that the impact of technology on CO2-EMS is insignificant.

Research Hypotheses

H1: There is a significant relationship between financial development and carbon dioxide emissions.

H2: There is a significant relationship between eco-innovation and carbon dioxide emissions.

Methodology

Data

This study gets secondary data from WDI for selected variables used in this study, which covers the period for China from 1980 to 2020. The dependent variable of the study is CO2-EMS in metric tons per capita (Zaidi et al., 2019). The first independent variable is FIN-DEV and the proxy used to calculate this variable is domestic credit provided by financial sector as a percentage of GDP (Anton & Nucu, 2020; Mukhtarov et al., 2020). Likewise, the second independent variable used in the study is eco-innovation and its proxy is patents (Razzaq et al., 2021). The study also used some control variables like the sum of imports and exports is used to measure TOP, industries including construction, value added as a percentage of GDP is used for industrialization and finally urban population as a percentage of total population is used as a proxy of urbanization (Cetin & Bakirtas, 2020).

Method

In order to examine the cointegration between FIN-DEV, eco-innovation (ECO-INO), industrialization (IND), trade openness (TOP), urbanization (URB), and, carbon dioxide emissions (CO2-EMS) outflow for the Chinese economy, this research employed the Auto Regressive Distributed Lag (ARDL) technique, developed and introduced by Pesaran et al. (2001), as well as

Pesaran and Shin (1995). Recent studies show that the ARDL methodology outperforms other approaches as those proposed by Johansen (1988), and Engle and Granger (1987) for estimating the co-integration relation. The ARDL technique is better as compared to other old techniques, firstly, because it is based on I (0) and I (1) assumptions. Secondly, this technique is also applicable to small data sets, and finally, it can be used to estimate long-term as well as short-term estimations between variables (Pesaran et al., 2001).

The association between financial development (FIN-DEV), eco-innovation (ECO-INO), and CO2-EMS was examined using the general model shown below.

$$CO2-EMS_t = \alpha_o + a_1\, t_t + a_2\, FIN-DEV_t + a_3\, ECO-INO_t + a_4\, TOP_t + a_5\, IND_t + a_6\, URB_t + \varepsilon_t \quad (1)$$

In equation 1, the dependent variable is CO2-EMS, while financial development (FIN-DEV) and eco-innovation (ECO-INO) are independent variables. The study also used some control variables in the study e.g., trade openness (TOP), industrialization (IND) and urbanization (URB) and Ɛ t is an error term. The error correction model is given as:

$$\Delta CO2-EMS_t = a_o\mu + \sum_{i=1}^{n} a_1 \Delta CO2-EMS_{t-i} + \sum_{i=1}^{n} a_2 \Delta lnFIN-DEV_{t-i} + \sum_{i=1}^{n} a_3 \Delta \ln ECO-INO_{t-i} + \sum_{i=1}^{n} a_4 \Delta \ln TOP_{t-i} + \sum_{i=1}^{n} a_5 \Delta lnIND_{t-i} + \sum_{i=1}^{n} a_6 \Delta \ln URB_{t-1} + \lambda_1 CO2-EMS_{t-1} + \lambda_2 FIN-DEV_{t-1} + \lambda_3 ECO-INO_{t-1} + \lambda_4 TOP_{t-1} + \lambda_5 IND_{t-1} + \lambda_6 URB_{t-1} + \beta_t + \varepsilon_t \quad (2)$$

The traditional F-statistics are used to evaluate these assumptions. We reject the null hypothesis that there is no co-integration and arrive to the conclusion that the variables are in a steady-state equilibrium if the estimated F-statistics are higher than the upper bound critical value. If the estimated F-statistics fall within the lower and upper bound critical values, the conclusion cannot be drawn. If the F-statistics value is more than the upper bound, cointegration is clearly present. In this case, establishing co-integration will be possible through the usage of the error correction term (Kremers et al., 1992). The next stage is to assess the accompanying ARDL error coercion models as well as the long-run coefficients of the same equation. The study uses the Akaike Information Criteria (AIC) to determine which ARDL model needs to be estimated and the best lag length to include in the model.

Equation 3 shows the result of short run relationship by using error correction model (ECM).

$$\Delta LCO2-EMS = a_o + \sum_{j=0}^{n} \beta_{FD} \Delta FIN-DEV + \sum_{j=0}^{n} \beta_{EI} \Delta ECO-INO + \sum_{j=0}^{n} \beta_{TOP} \Delta TOP + \sum_{j=0}^{n} \beta_{IND} \Delta IND + \sum_{j=0}^{n} \beta_{URB} \Delta URB + \eta ECM_{t-1} + \varepsilon_t \quad (3)$$

The short-run change procedure is looked at from an ECM standpoint. If the coefficient of ECM is between 0 and -1, a portion of the error in period t-1 is used to calculate the correction to CO2-EMS in period t. In this situation, in response to changes in the exogenous variables, the ECM drives the CO2-EMS to monotonically converge to its long-run equilibrium path. The ECM will cause the CO2-EMS to diverge if it is positive or less than -2.

Findings

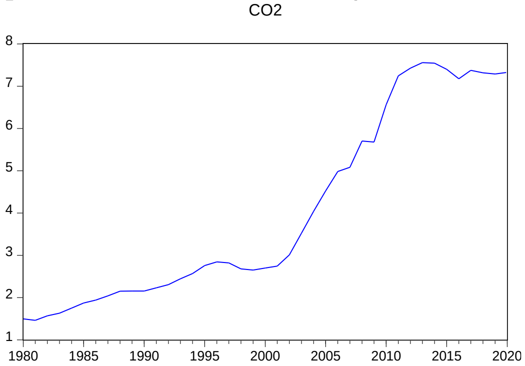
Descriptive Statistics

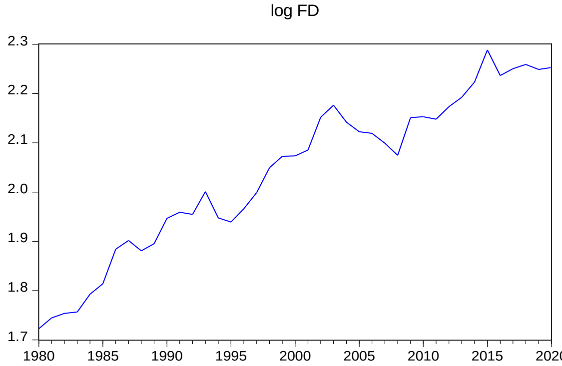
The summary metrics of the provided data set are described by the descriptive statistics. According to Table I. The average CO2-EMS value is 4.0408, with a minimum value of 1.4604 and a high value of 7.5572. Additionally, the mean value of the independent variable FIN-DEV is 2.0390, with a minimum value of 1.7226 and a maximum value of 2.2287. The average value of ECO-INO is 4.6421, with minimum and highest values of 3.5433 and 6.1442, respectively. The mean values of industrialization, TOP, and urbanization, respectively, for control variables, are 44.2496, 37.1261, and 38.0304, with lowest and maximum values of 37.8209, 12.4248, and 19.3580, respectively.

Table I: Descriptive Statistics

	Observations	Mean	Std. Dev.	Minimum	Maximum
CO2-EMS	41	4.0408	2.2525	1.4604	7.5572
FIN-DEV	41	2.0390	0.1627	1.7226	2.2887
ECO-INO	41	4.6421	0.9324	3.5433	6.1442
IND	41	44.2496	2.6549	37.8209	48.0576
TOPS	41	37.1261	13.5540	12.4248	65.6189
URB	41	38.0304	13.0962	19.3580	61.4280

The time series graphs of the variables employed in the analysis are shown in Figure I. The distribution of the CO2-EMS, TOP, FIN-DEV, Industrialization, ECO-INO, and, urbanization is shown through 1980–2020. According to Figure I, China's CO2-EMS started rising in 1980 and then started to modestly fall between 1997 and 2001. However, from 2002 to 2015, it started to grow again due to an increase in energy consumption. Since 1980, the nation has pursued FIN-DEV, and its performance has increased and a little decline occurs from 2003- 2007 but it rises again in the subsequent years frequently. ECO-INO indicate a tremendous increasing trend from 1980 to 2020. The variable that capture industrialization shows a slight decreasing trend in a given sample period from 1980, shows an increase from 1995 to 2010 and then again shows a decline from 2010 to 2020. For the sample period, China's level of TOP is extremely unpredictable; the plot showed a higher level of TOP around 2005, but started declining around 2015 up to 2020. Finally, the variable urbanization shows an increasing trend from 1980 to 2020 selected time period for Chinese economy.





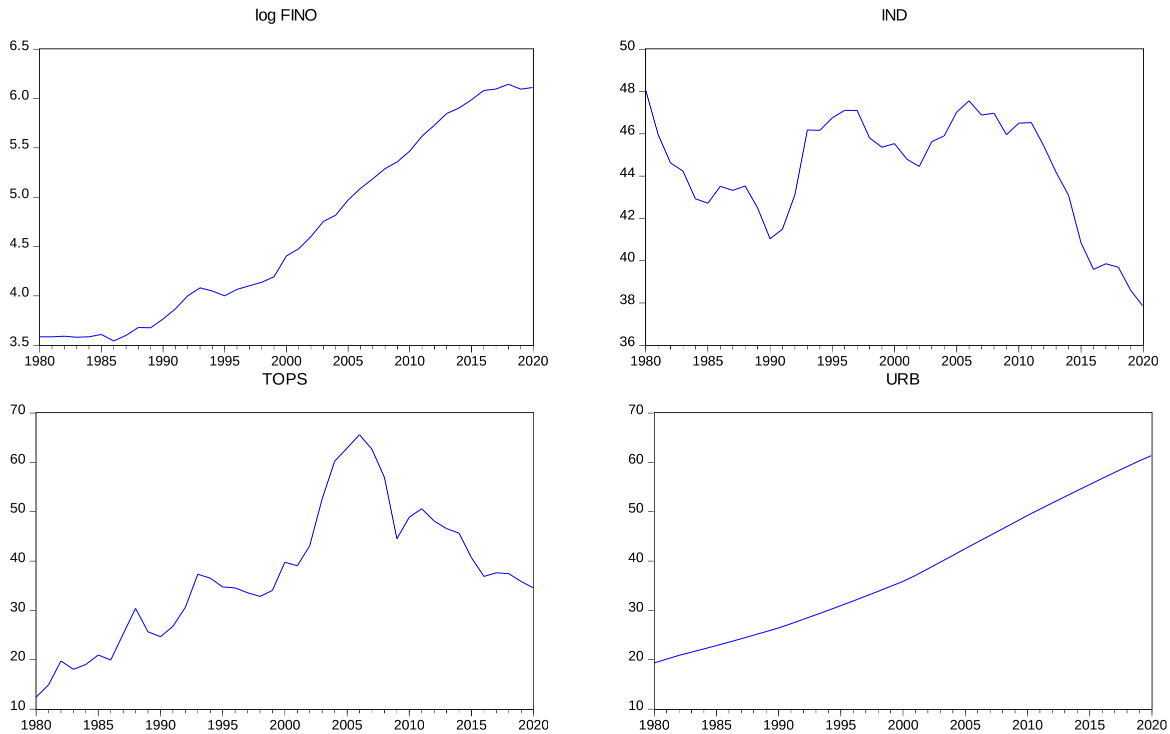


Figure I: Time plots series of the variables

Unit Root Test

To determine the variables' order of integration before estimating the main model, we calculated unit roots using ADF and PP models. The findings of Table II show the results of ADF and PP unit root tests. The findings show that the variable urbanization is stationary at a level with an order of integration of 1(0), whereas the remaining five variables, such as CO2-EMS, financial development, eco-innovation, industrialization, and TOP, are stationary at a first difference with the order of integration of 1(1), respectively. Being able to accommodate the combination of I (0) and I (1) variables in the model makes ARDL a suitable method to use (Pesaran et al., 2001).

Table II: Unit root tests results

Variables	ADF		PP		Order of Integration
	Constant without trend	Constant with trend	Constant without trend	Constant with trend	
Level					
CO2-EMS	-0.317199	-2.286981	-0.080382	-1.793836	-
FIN-DEV	-1.522041	-2.554889	-1.632686	-2.620256	-
ECO-INO	0.332351	-2.410465	0.734443	-2.486834	-
IND	-1.027536	-1.225712	-1.132899	-1.252671	-
TOPS	-1.888895	-1.301233	-1.891273	-0.938232	-
URB	-1.117932	-4.063124**	3.927261	-2.254042	I(0)
First Difference					
CO2-EMS	-3.841725***	-3.783811**	-3.947117***	-3.902541**	1(1)
FIN-DEV	-6.274044***	-6.324312***	-6.312336***	-6.466510***	1(1)
ECO-INO	-3.872146***	-3.910418**	-3.891199**	-3.972888**	1(1)
IND	-4.099056**	-4.203229**	-4.103839**	-4.131049**	1(1)
TOPS	-4.322152**	-4.560997**	-4.322152**	-4.526891**	1(1)

URB	-1.193465	-0.156681	-1.202142	-0.594625	-
*, **, ***Significance level at 10, 5, and 1% respectively					

Lag Length Selection

Table III applies different criteria to determine the ideal lag length for the model. Since lag length 4 has the lowest FPE, AIC, and HQ values, it is chosen based on LR, FPE, AIC, and HQ, suggesting that it provides the optimum trade-off between model fit and complexity. Lag length 4 is the best option because it meets all other criteria and is the most comprehensive fit, even though SC favors simpler models.

Table III: Criteria for lag length

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-254.1021	NA	0.051426	14.05957	14.32080	14.15167
1	112.5484	594.5684	9.14e-10	-3.813426	-1.984816*	-3.168755
2	162.1476	64.34490	5.14e-10	-4.548517	-1.152528	-3.351272
3	209.7372	46.30338	4.36e-10	-5.174981	-0.211613	-3.425161
4	300.0852	58.60416*	6.92e-11*	-8.112715*	-1.581967	-5.810320*

* indicates lag order selected by the criterion

Cointegration Result

Table IV shows the findings of the ARDL cointegration test. The estimated F-statistics (4.3512) exceeds the critical upper bound values. The fact that we reject the null hypothesis at the 5% level of significance indicates that the variables are cointegrated. We now estimate our long-run coefficients because the long-run relationship has been established; the outcome is displayed in Table V.

Table IV: ARDL bound test result

Estimation	Lag length	F-statistics	Significance level (%)	Critical bound F-statistics Lower Bound 1(0)	Upper Bound 1(1)
$F_{CO2-EMS}$ (FIN-DEV/ECO-INO/IND/TOPS/URB)	4	4.3512	10%	2.08	3
			5%	2.39	3.38
			1%	3.06	4.15

Table V: Long-run coefficients result

Regressors	Coefficients	T-ratio (*p* value)
Constant	-16.8721	-3.7266 (0.0047)***
FIN-DEV	-5.2394	2.7602 (0.0221)**
ECO-INO	-4.2282	8.7408 (0.0000)***
IND	0.0057	-0.2045 (0.8425)***
TOPS	-0.0172	2.1108 (0.0640)***
URB	0.1828	-4.1965 (0.0047)***
CO2-EMS = -16.8721 - 5.2394*FIN-DEV - 4.2282*ECO-INO +0.0057*IND - 0.0172*TOPS + 0.1829*URB		

Table VI: Short-run coefficients result

Regressors	Coefficients	T-ratio (*p* value)
D (CO2-EMS)	1.9364	7.5345 (0.0000)***
D(FIN-DEV)	2.4972	3.1097 (0.0125)**
D(ECO-INO)	-4.6611	-6.2905 (0.0001)***
D(IND)	0.2588	5.3098 (0.0005)***
D(TOPS)	-0.0424	-4.7771 (0.0010)***
D(URB)	1.4900	-2.9132 (0.0172)**
Coint Eq (-1)*	-1.7979	-7.1248 (0.0001)***
R square	0.9398	
D.W	2.4575	

Discussion

The results of the current study show that, in the short run, FIN-DEV has a significant positive association with CO2-EMS. This means that when FIN-DEV increases in China, it also stimulates CO2-EMS to grow. Therefore, when CO2-EMS rise as a result of FIN-DEV, environmental quality is being negatively impacted. The findings of this research are corroborated by Shahbaz et al. (2020) and Wang et al. (2020). However, the long-term impact of FIN-DEV on CO2-EMS is negative and statistically significant, suggesting that FIN-DEV slows down environmental deterioration. The fact that this variable's coefficient has a negative sign indicates that the financial industry in China has matured, as seen by the fact that it invests in eco-friendly projects and encourages businesses to employ advanced technology in production to boost output. This outcome is supported by Jalil and Feridun (2012). The link between the variables ECO-INO and CO2-EMS is significantly inverse, and the results indicate that an increase in ECO-INO results in a drop in CO2-EMS. Our findings are validated by the result of Ji et al. (2020); Razzaq et al. (2021); Wang et al. (2020). The endogenous growth theory backs up the claim that technological innovation has had a significant impact on raising environmental quality. According to this notion, technological advancement increases a country's capacity to switch out polluting resources with more environmentally friendly ones. Additionally, improvements and technical developments can reduce energy use, that lessens environmental deterioration.

Additionally, there is a significant relationship between industrialization, TOP, and urbanization with CO2-EMS. The findings for variable industrialization revealed that increase in industrialization has increased CO2-EMS in china and reduced environmental quality and the results are similar with Li and Liu (2015); Mahmood et al. (2020) and Ullah et al. (2020). Our findings for TOP show that increase in TOP leads to decrease CO2-EMS in China. These findings match with Shahbaz et al. (2013). Finally, for urbanization the results shows that increase in urbanization leads to increase in CO2-EMS emissions in China. This finding is also in line with Li and Liu (2015); Mahmood et al. (2020). Table VI shows the result of short-run coefficients results.

The findings from the short-run dynamics presented in Table VI revealed that urbanization, industrialization, and TOP have a significant relationship with CO2-EMS. However, FIN-DEV have a significant positive impact on CO2-EMS in the short-run and the long run. The econometric theory states that the coefficient value in an error correction model must be negative, which actually indicates the convergence of the short run to the long run and confirms the presence of a long-run relationship between two variables (Banerjee et al. 1998).

Conclusion

This study investigates the dynamic relationship in China between carbon dioxide emissions (CO2-EMS), financial development (FIN-DEV), and eco-innovation (ECO-INO). The study used ARDL bound test approach to check the said relationship by using annual data for the period 1980-2020. According to the study's conclusions, ECO-INO, TOP and FIN-DEV all have a considerable negative impact on CO2-EMS in the long run. The notion is supported by the endogenous growth theory, which holds that advancements in technology increase a country's capacity to switch out polluting resources for more ecologically friendly ones. It demonstrates that for China, rising financial development and eco-innovation is beneficial for lowering CO2-EMS.

The research's findings have important policy implications because they highlight the difficulty that China's policymakers face in striking a balance between advancing FIN-DEV and enhancing environmental quality at the same time. Authorities need to investigate alternate energy sources (such as green energy) in order to decrease the country's ongoing environmental damage brought on by excessive fossil fuel use, which raises CO2-EMS levels, depletes the ozone layer, and hence increases global warming. Another option for policy makers is to adopt appropriate TOP policies that will aid in lowering CO2-EMS levels and thereby enhance environmental quality. The study's findings also showed that ECO-INO is viewed as a long-term tool that will help in reducing CO2-EMS that operate through a variety of channels (green energy consumption, green energy projects, and R&D in energy-related patents). The development of the financial sector should continue, with a particular emphasis on initiatives that offer rewards for the amelioration of environmental deterioration. The efforts of the public and commercial sectors to implement green policies and make green investments can support the growth of the national economy and increase its global competitiveness. Given the new knowledge transfers, it is important to promote urbanization and open trade. The idea of "green urbanization" has the potential to significantly reduce CO2-EMS.

This work considerably increases our knowledge of how FIN-DEV and ECO-INO affect environmental sustainability by using the Auto Regressive Distributed Lag (ARDL) technique. It offers empirical evidence in favor of the endogenous growth theory, proving that rising financial development and scientific progress can both successfully cut carbon dioxide emissions. The study offers practical insights for policymakers in China and similar contexts by integrating environmental dimensions into this theoretical framework. This integration enhances the theory and highlights the significance of combining financial and eco-innovation strategies for sustainable development.

There are a few noteworthy limitations to the study. First off, relying only on annual statistics could ignore recent trends and short-term variations. Furthermore, the linear relationship assumption of the ARDL model may fail to account for any nonlinear dynamics. The environmental impact assessment's breadth is limited by its exclusive concentration on CO2 emissions as an environmental indicator, and its conclusions might not apply to other countries. Moreover, even if the ARDL method mitigates certain endogeneity issues, unobserved variables might still have an impact on the outcomes. These limitations imply that in order to improve the robustness of the results, future study should investigate more detailed data, more environmental indicators, and alternative analytical techniques.

To assess the effect of FIN-DEV and eco-innovation on CO2-EMS, future research is more likely to duplicate this study by including additional economies. To assess the impact of eco-innovation and financial development on CO2-EMS, our study concentrated on a particular set of variables. To better understand how these variables contribute to the reduction of environmental pollution, additional research can be conducted in other economies by using some other variables.

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