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| RESEARCH ARTICLE

The Role of Green Technological Innovation, Fintech, and Financial Development in Environmental Sustainability: A Study on Selected Asian Countries

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| ABSTRACT
This study intends to explore the nexus of green technological innovations, financial development, and Fintech with environmental sustainability. It employs data from Asian economies spanning from 2012 to 2021. We intend to examine the impact of green innovations, Fintech, and financial development (measured through access to financial institutions and efficiency of financial markets) on Environmental Sustainability (measured through carbon emissions). After addressing the issues of slope heterogeneity, cointegration, and CSD, this study employs the CS-ARDL model to explore the connectedness between proposed variables. We find that Fintech and the efficiency of financial markets enhance carbon emissions, thus deteriorating environmental sustainability. On the other hand, access to financial institutions and green technological innovations improves ecological sustainability. The findings are essential for Asian economies and policymakers to attain better environmental quality.

| KEYWORDS

Carbon Emissions; Environmental Sustainability; Fintech; Green Innovations; Financial Market Efficiency; Access to Financial Institutions

| ARTICLE INFORMATION

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1. Introduction

Green innovation helps reduce the adverse impacts of production processes on the environmental ecosystem by preventing pollution, recycling waste, and conserving energy (Irfan, 2022). Green innovation not only reduces carbon emissions but also makes commercial business sense. The achievement of net zero carbon emissions has received more attention in the literature concerning SDGs (Liu, 2022). Many countries have made tremendous efforts to promote green technologies; for example, China is promoting green innovation (Liu, 2022) in the IT field via the Green Technology Bank, given its higher Carbon dioxide emissions compared to other Asian countries. Although Climate technologies have shown an upward trend in recent years, carbon emissions have posed a considerable challenge for Asian economies.

The impact of financial development on climate sustainability has also received attention from the former leaders of climate deterioration (Wang, 2020). Financial development leads to improved access to capital and increased investment opportunities, increasing energy consumption and higher carbon dioxide emissions. Similarly, the efficiency of capital and financial markets lowers liquidity restrictions, opens new investment opportunities, causes an increase in energy demands, and thus enhances pollution (Wang, 2019; Ma, 2020). Most recent studies employ a single proxy to investigate the connection between financial advancements and carbon emissions; however, the current study uses a wide range of proxies to measure the financial advancement in Asian economies (see Table 1 for details).

Fintech has been recognized as a driver of economic growth; however, it may also affect climate quality. Fintech improves access to finance for businesses and consumers; however, Fintech operations consume vast energy levels, and E-waste deteriorates the climate quality[6]. Few studies have investigated the nexus of Fintech, Financial development, and Green Innovations with Environmental sustainability in the context of Asian economies. By employing advanced panel estimation techniques, the results reveal that Fintech and the efficiency of financial markets deteriorate environmental sustainability while green innovation and access to finance improve it. The article is structured as follows: the upcoming section provides a literature review; the Methodology is offered in section 3. Section 4 offers empirical outcomes, while the conclusion and recommendations are addressed in Section 5.

2. Literature review

Green technological innovation is considered effective in managing environmental sustainability. In this context, Chien et al. (2021) apply the moments-quantile regression technique and observe how green technological innovations enhance climate sustainability. Lin & Ma (2022) investigate the connectedness of green technological innovations with climate quality and find the relationship to be positive in regions with higher human capital developments. The connection between financial development and climate quality has been investigated in different studies, where authors report heterogeneous associations. Zhang (2011) investigated the relationship in China and reported that financial development derives the climate quality. Taking data from 35 OECD countries, Lu et al. (2022) investigate the impressions of green technologies and democracy on the growth rate of carbon emissions. The authors find that green technological adoption and democracy reduce carbon emissions. The authors further observe that trade liberalization enhances carbon emissions and reduces climate quality.

Amin et al. (2020) argue that the efficiency of the financial system improves access to finance, which results in higher energy utilization, higher pollution, and deterioration of climate quality. In this context, Khan et al. (2020) have reported similar findings using a global sample. However, Sheraz et al. (2021) investigated G20 economies and explored the dynamic impressions of financial advancement on carbon emissions. The authors argue that financial growth enhances the provision of finances for adopting green industrial innovations. They find that financial advancements mitigate carbon emissions and improve climate sustainability. Koondhar et al. (2021) explore the impact of financial growth on climate quality in China from 1998 to 2018. Using long- and short-run correlational techniques, the authors find a positive connectedness between financial advancement and environmental degradation. Using data from four decades, Li and Wei (2021) investigated 30 provinces in China and found that financial development adversely affects climate quality.

Muganyi et al. (2021) extensively analyze the effects of fintech development and green finance legislation on industrial carbon emissions from 2011 to 2018. Policies about green finance have been found to significantly lower carbon emissions, and fintech development has been shown to have comparable effects on projects that qualify as investments in environmental protection. More recently, Tan et al. (2023) argue that Fintech effectively enhances resource allocation, which has a favorable effect on the quality of the climate. Moreover, Fintech makes it easier for businesses to support green technological breakthroughs by offering innovative goods and services. According to Muhammad et al. (2022), using fintech improves environmental quality. According to Li et al. (2023a), financial digitization improves the proportion of clean energy consumed in total energy consumption and increases the green total factor of production. As a result, fintech has a beneficial impact on climate quality. The literature review cited above suggests that green innovations, financial advancements, and Fintech are essential factors to consider when analyzing trends in carbon emissions.

Variables	Measurement	Abbreviations	Data-Source
Environmental Sustainability	CO_2 Emissions	ES	WDI
Fintech	Digital Fund Raising	Fintech	
Green Innovations	Environmental Change Mitigation Patents	ECMP	OECD.stat
Financial Development	Access to Financial institutions Efficiency of Financial Markets	AFinIn, EFinMar	IMF.org

Table 1: Summary of Variables

3. Data Description and Methodology

To achieve the objectives, the study initially explores the CSD (cross-sectional-dependence) arising from residuals, COVID-19-related volatility, macroeconomic indicators, and global shocks. Salim et al. (2017) and Westerlund (2008) argue that the issue of CSD should be addressed appropriately to avoid biases in econometric analysis. Hence, the study employs Pesaran's (2015) CSD test. After investigating the CSD characteristics, we examine the stationarity of the data series used in the study. Examination of stationarity property is necessary for panel data analysis. For stationarity issues, Levin et al. (2002) assume that mostly homogeneous panel data have stationarity problems. Im et al. (2003) argue that heterogeneous panel data is more prone to unit root issues. After inspecting the CSD and unit root properties, the study explores the existence of heterogeneity of slope parameters using the econometric approach suggested by Pesaran and Yamagata (2008). The test's null hypothesis assumes the existence of slope homogeneity, while H1 denies it. The next step is to gauge whether long-run cointegration prevails between variables used in the current study. In this regard, Westerlund and Edgerton (2008) suggest that panel-cointegration models better cope with the heterogeneity of slope parameters, the CSD, and serial correlation in error terms. Similarly, the cointegration test of Banerjee and Carrion-I Silvestre (2017) also aids in coping with heterogeneity of slope parameters, the CSD, and serial correlation in error terms in panel data. Çoban and Topcu (2013) suggest employing the CS-ARDL model to appropriately address issues like slope heterogeneity, structural breaks, and CSD.

In the current study, Environmental Quality (EQ) is the dependent variable, while independent variables include Fintech, financial advancement, and green environmental innovations. The proposed connectedness between the variables is given in the following equation.

$$ES_{i,t} = f\ (Fintech_{i,t}, AFinIn_{i,t}, EFinMar_{i,t}, ECMP_{i,t}) \qquad (1)$$

The symbol i represents the Cross sections (countries), and the period is indicated with *t*. The function presented in Equation 1 is further expressed via the following regression equation:

$$ES_{i,t} = \alpha_{1it} + \alpha_{2it}EPT_{it} + \alpha_{3it}GBonds_{it} + \alpha_{4it}FinME_{it} + \alpha_{5it}AFinI_{it} + \beta_i + \delta_i \qquad (2)$$

$$W_{i,t} = \sum_{i=0}^{pw} \varphi_{i,t}\, W_{i,t-1} + \sum_{i=0}^{pz} \gamma_{i,t}\, Z_{i,t-1} + \varepsilon_{i,t} \qquad (3)$$

Equation 3 exhibits the ARDL model, which is extended to account for the CSD and presented in equation 4:

$$W_{it} = \sum_{i=0}^{pw} \varphi_{i,t}\, W_{i,t-1} + \sum_{i=0}^{pZ} \gamma_{i,t}\, Z_{i,t-1} + \sum_{i=0}^{pX} a_i\, \bar{X}_{t-1} + \varepsilon_{i,t} \qquad (4)$$

In Equation 4, W_{it} indicate the environmental sustainability (the dependent variable), whereas all independent variables are expressed via the term $Z_{i,t-1}$. The study expresses the average values of independent and dependent variables via $\bar{X}_{t-1}$ to avoid the potential problem of CSD associated with spillover effects. Moreover, P_w, P_z, and P_x present the lagged values for variables. The following econometric expression indicates the mean group and long-run estimators;

$$\hat{\pi}_{CD-ARDL,i} = \frac{1}{1 = \Sigma_I = 0} \sum_{I=0}^{pz} \hat{\gamma}_{Ii}\, \hat{\varphi}_{I,t} \qquad (5)$$

$$\hat{\bar{\pi}}_{MG} = \frac{1}{N} \sum_{i=1}^{N} \hat{\pi}_i \qquad (6)$$

The parameters for the short run are expressed as:

$$\Delta W_{it} = \vartheta_i\left[W_{i,t-1} - \pi_i Z_{i,t-1}\right] - \sum_{i=0}^{pw-1} \varphi_{i,t}\Delta_i W_{i,t-1} + \sum_{i=0}^{pz} \gamma_{i,t}\Delta_i Z_{i,t-1} + \sum_{i=0}^{px} \alpha_i \bar{X}_t + \varepsilon_{i,t} \qquad (7)$$

Where Δi = t − (t − 1) in the above econometric model;

$$\hat{\tau}_i = -\left(1 - \sum_{i=0}^{pw} \hat{\varphi}_{i,t}\right) \qquad (8)$$

$$\hat{\pi}_i = \frac{1}{\hat{\tau}_i} \sum_{i=0}^{pz} \hat{\gamma}_{i,t} \qquad (9)$$

$$\hat{\bar{\pi}}_{MG} = \frac{1}{N} \sum_{i=1}^{N} \hat{\pi}_i \qquad (10)$$

The study employs Correlated Effects Mean Group (CCEMG) and Augmented Mean Group (AMG) estimators proposed by Pesaran (2006) and Eberhardt and Teal (2010), respectively, to check the robustness of the results. The said econometric models better cope with CSD, heterogeneity, and structural break issues. The summary of variables and their data sources are presented in Table 1. The data is collected from Asian economies over the period from 2012 to 2021. The period Also includes the COVID-19 pandemic era. Table 2 represents the descriptive statistics.

	ES	FINTECH	ECMP	EFINMAR	OPINION
Mean	1.88E+09	2442.450	211.7467	0.200000	0.033333
Maximum	1.15E+10	16540.00	2438.800	1.000000	1.000000
Minimum	5274698.	0.000000	0.000000	0.000000	0.000000
Std. Dev.	3.81E+09	5111.107	522.6408	0.403376	0.181020

Table 2: Summary of Descriptives.

Variables	t-Statistics.
ES	35.873***
Fintech	26.119***
AFinIn	31.364***
EFinMar	34.093***
ECMP	29.551***

Table 3: Outcomes for CSD (Note: * expresses significance at 1 % confidence interval)**

4. Results and Discussion

In the first step, the study explores the CSD properties of the data series with the application of the CSD test introduced by Pesaran (2015), having a null hypothesis of "the existence of no significant CSD" along with a null hypothesis implying an absence of CSD. Table 3 presents that all the variables reject the null hypothesis of the absence of CSD because the coefficients are significant at 1 %, indicating the presence of CSD. In the next step, the unit root tests of Bai and Carrion-I-Silvestre (2009) and Pesaran (2015) are applied to uncover the stationarity of the data series. Table 4 exhibits the coefficients of the unit root model of Pesaran (2015), and the coefficient values confirm that all the variables are stationary at the level. However, the null hypothesis of stationarity is rejected at the level with the application of the test proposed by Bai and Carrion-I Silvestre (2009). Because this test accounts for the structural changes, therefore the null hypothesis of stationarity is accepted when the first difference is taken. The results for stationarity are presented in Table 4.

Panel A: Pesaran (2007) tests for structural breaks				
	I(0)		I(1)	
Variables	CIPS	MCIPS	CIPS	MCIPS
ES	-6.749**	-7.366***	-10.284***	-13.309***
Fintech	-5.394**	-6.395**	-10.323***	-12.882***
AFinIn	-5.028***	-7.294***	-12.884***	-16.399***
EFinMar	-6.244***	-6.110**	-14.190***	-12.103***
ECMP	-7.435***	-4.234**	-18.385***	-16.001***

Panel B: Bia and Carrion-i-silvestre (2009)						
		I(0)			I(1)	
	Z	Pm	P	Z	Pm	P
ES	0.183	0.847	18.76	-4.294***	7.753***	93.223***
Fintech	0.284	0.639	20.93	-5.883***	7.001***	64.757***
AFinIn	0.743	0.744	21.11	-5196***	5294***	69.939***
EFinMar	0.537	0.649	20.00	-4.240***	6.395***	70.103***
ECMP	0.364	0.410	21.29	-3.295***	8.365***	64.944***

Table 4: Unit-root test coefficients. (Note: *, **, & * declare the significance levels at 1 %, 5%, & 10% respectively)**

As discussed in the methodology, the study assesses the slope heterogeneity to avoid biases in further analysis. The null hypothesis implies that slope coefficients are homogeneous. The outcomes in Table 5 are significant at a 1 % level of confidence; therefore, the null hypothesis is rejected, and the table values claim that slope coefficients are heterogeneous.

DV: ES	
	t-score (Sig.)
Δ-tilde	35.361***
Δ-tilde Adjusted	39.944***

Table 5: Coefficients for slope heterogeneity. Note: * indicates the level of significance with a 1 % confidence interval.**

After the examination of slop heterogeneity, cointegration properties are examined with the application of the cointegration test proposed by Westerlund and Edgerton (2008). The test implies a null hypothesis, i.e., the absence of cointegration under the presence of CSD. Table 6 indicates that coefficients of the cointegration test with a regime shift, mean shift, and no break are highly significant. Hence, the null hypothesis is rejected, and the alternative is accepted, which implies the existence of cointegration. The current study also employs the cointegration test suggested by Banerjee and Carrion-i-Silvestre (2017) under three different scenarios, i.e., with trend, constant, and deterministic specification. Table 6 also presents the cointegration outcomes of Banerjee and Carrion-i-Silvestre (2017) test at country levels. The coefficients again exhibit the presence of cointegration among variables in the long run.

Coefficients of panel cointegration tests of Westerlund and Edgerton's (2008)			
Test Dependent Variable: ES	No-break	Mean-shift	Regime-shift
Zφ(N)	-4.743***	-5.846***	-5.443***
Zτ(N)	-5.001***	-4.374***	-4.194***
Panel	No deterministic specification	At constant	At trend
Coefficients of cointegration tests of Banerjee and Carrion-i-Silvestre (2017).			
Cambodia	-7.885***	-4.694***	-4.260***
China	-5.093***	-5.107***	-3.094***
Indonesia	-7.561***	-4.440***	-4.629***
Malaysia	-5.935***	-5.294***	-4.615***
Philippines	-5.638***	-4.294***	-4.629***
Singapore	-5.023***	-4.198***	-5.856***

Table 6: Cointegration Outcomes. Note: * indicates the level of significance with a 1 % confidence interval.**

Table 7 exhibits coefficients for CS_ARDL in both the short and long run. As discussed in the methodology, Environmental Sustainability is measured through carbon emissions. In the long run, fintech has a positive connection with carbon emissions, indicating that a 1 % advancement in Fintech causes a 0.496 % increase in carbon emission. Hence, Fintech development needs to improve Environmental sustainability in sample economies. Green innovations (ECMP) have a negative association with carbon emissions, indicating that a 1 % increase in green innovations causes a 0.186% decline in carbon emissions, hence enhancing environmental sustainability. The findings are similar to the outcomes of a study conducted by He et al. (2021), who found that green technological advancements reduce carbon emissions.

The efficiency of financial markets (EFinMar) has a positive and significant impact on carbon emissions. Financial market efficiency enhances economic growth, which in turn deteriorates climate sustainability. The findings are similar to the outcomes of the study of Odugbesan and Adebayo (2020), who found a positive association between financial advancements and carbon emissions in Nigeria[28]. Finally, we find significant negative impressions between access to financial institutions and carbon emissions, where a 1% increase in access to financial institutions brings a 0.281% decrease in carbon emissions. The results are similar to the study of Amin et al. (2020), who found significant connections between access to financial institutions and environmental sustainability in G10 economies. Table 7 also presents the outcomes of the CS-ARDL model in the short run, where the coefficients infer similar results as the long-run analysis exhibits. Via Table 8, the current study checks the robustness of outcomes obtained with the application of the CS-ARDL model. It is clear from the coefficient values that both AMG and CCEMG support the results of the CS-ARDL model.

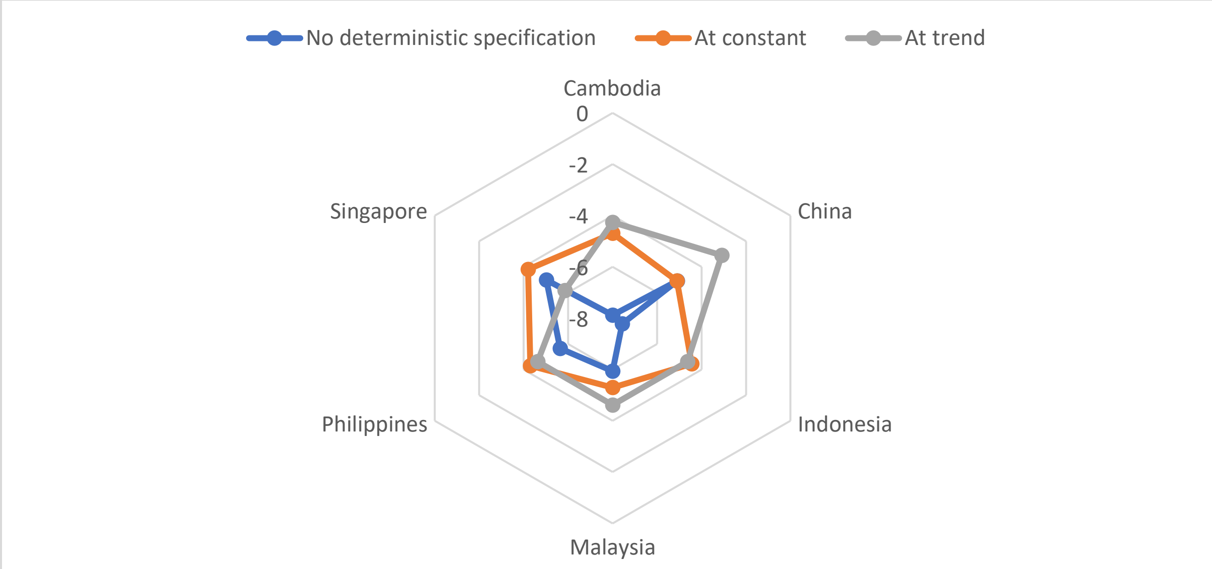

Figure 1. Coefficients of cointegration tests of Banerjee and Carrion-i-Silvestre (2017).

	β	t-stat
	Long-Run	
Fintech	0.496***	4.735
AFinIn	-0.281**	-2.029
EFinMar	0.179***	5.475
ECMP	-0.186***	-4.903
CSD-Stat	-0928	0.031
	Short-Run	
Fintech	0.519**	4.193
AFinIn	-0.328**	-3.23
EFinMar	0.201**	2.74
ECMP	-0.256***	-4.13
ECT(− 1)	-0.256***	-5.08

Table 7: Outcomes of CS-ARDL model (Note: *, **, & * declare the significance levels at 1 %, 5%, & 10% respectively)**

Variables	AMG		CCEMG	
	α	t-stat	*α*	t-stat
Fintech	0.54***	6.843	0.58***	5.662
AFinIn	-0.304**	-2.846	-0.322**	-2.01
EFinMar	0.294***	4.945	0.298**	2.773
ECMP	-0.236**	2.120	-0.203***	-3.294
Wald test	–	29.844	–	39.120

Table 8: Coefficients of Robustness Checks (Note: * indicates the level of significance with a 1 % confidence interval. While ** & * indicate the same for 5 % & 10% confidence intervals).**

5. Conclusion and policy implications

Climate change is a serious problem faced by almost every country. UN has defined 17 sustainable development goals for innovation, structure, industry, and climate. Numerous studies have investigated the impact of financial advancement on climate change. However, few studies have investigated the impact of the efficiency of financial markets, access to financial institutions, and fintech on climate quality. Moreover, little attention is paid to climate-related green innovation. Therefore, the study investigates the impressions of Fintech, financial advancements, and green innovations on environmental sustainability. The study collects data from the years 2012 to 2021, which also includes data on the COVID-19 period. The Asian economies are selected for analysis. The study initially discovers the cross-sectional dependencies and confirms the stationarity of series and slope heterogeneity. It is further observed that cointegration is present among variables with regime shift, mean shift, and no break, with trend, constant, and deterministic specification. To explore the causal connections between dependent and independent variables, the current study employs the CS-ARDL mode. It is clear from the results that Fintech enhances carbon emissions and damages environmental sustainability in both the short- and long-run.

The efficiency of financial markets plays a similar role. However, we find that access to financial institutions helps to reduce carbon emissions and enhances climate sustainability because, inside a sustainable financial system, funding and investment operations are now open to green energy projects in Asian economies, hence leading to reduced emissions of greenhouse gases and carbon. Such a green financial environment should be encouraged to offer sustainable financing instruments to protect the climate quality. Moreover, green technologies, i.e., climate change mitigation patents, enhance environmental quality because such technologies reduce the emission of carbon dioxide. The results for the short run are almost similar with the same sign of coefficients, but we observe slightly higher values of coefficients in the short run. To test the robustness of coefficients generated by CS-ARDL, the study employs AMG and CCEMG econometric models. Both estimators produce the same coefficients as obtained via the CS-ARDL model.

Based on the findings, we recommend that Asian economies use green sources of energy behind Fintech mining. The countries should replace traditional technologies with environmentally friendly technologies. In this regard, the government should prohibit industry from utilizing conventional energy sources and impose heavy taxes on enterprises that pollute the environment. We recommend that the economies under study enhance the climate regulations in financial markets to provide an environmentally friendly financial ecosystem. Future research may be done in other economies using time series data and robust GARCH models. Future researchers may compare the Asian economies with European or Middle Eastern economies to explore regional environmental sustainability. We recommend that future researchers explore the model of this study by utilizing the different market conditions and sub-sample approach proposed by Shahid and Sattar (2017) to assess the time variation of connectedness.

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