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Abstract

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Keywords: Fintech, Financial Inclusion; Social Welfare; Environmental Quality, Economic Development; Green Innovation

Authors:

Muhammad Ishtiaq: Associate Professor, Lyallpur Business School, Government College University, Faisalabad, Punjab, Pakistan.

Falak Sher: Assistant Professor, Government College University Faisalabad, Chiniot Campus, Punjab. Pakistan.

Muhammad Naeem Shahid: (Corresponding Author) Assistant Professor, LBS, Government College University Faisalabad, Chiniot Campus, Punjab. Pakistan.
Email: (drmnaeemshahid@gcuf.edu.pk)

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Abstract

The study uncovers the connection between financial inclusion, Fintech, Green Innovation, and social welfare with China's environmental quality and economic development. Employing macroeconomic data from 2014-2023 and using the QARDL model, we find that social welfare and green innovation enhance climate quality while financial inclusion and Fintech deteriorate it. All the independent variables, however, significantly improve economic development. Also, all variables exhibit bidirectional causality with economic growth, except climate quality, which depicts both unidirectional and bidirectional causality. Our results imply that the Chinese government should enhance financial inclusion and Fintech growth for economic sustainability. However, the country should focus on renewable energy consumption related to Fintech growth and optimize financial inclusion to avoid environmental deterioration. More spending on social welfare could enhance human capital and environmentally conscious behavior. This study provides important insights for policymakers in China in allocating resources to balance economic and environmental sustainability.

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Authors:

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Falak Sher: Assistant Professor, Government College University Faisalabad, Chiniot Campus, Punjab. Pakistan.

Muhammad Naeem Shahid: (Corresponding Author) Assistant Professor, LBS, Government College University Faisalabad, Chiniot Campus, Punjab. Pakistan.
Email: (drmnaeemshahid@gcuf.edu.pk)

Introduction

Long-term economic growth depends upon balancing environmental, social, and economic sustainability. Collaborative efforts among governments, businesses, and communities and incentives ensure economic development while mitigating environmental degradation. Environmental sustainability ensures natural resources and ecosystem preservation, critical for industry, agriculture, and climate, ultimately affecting economic growth. Environmental conservation avoids disasters and systemic risks to businesses, reduces costs, and improves efficiency, leading to sustained economic growth. Also, conserving natural habitats and biodiversity has resulted in many countries attracting eco-tourism, contributing to economic development. By balancing environmental and economic considerations, we can achieve long-term economic prosperity and ecological resilience, contributing to a sustainable future for all (Wiedmann et al., 2020).

In this paper, we intend to study the factors impacting economic and environmental sustainability in China. Studying China is crucial as its economy is currently the second largest, one of the fastest growing, and is expected to be the world's largest economy by 2050. Concurrently, China ranks at the top for carbon emissions, and for policymaking, it is essential to concentrate on drivers that could strike an equilibrium between economic advancements and ecological sustainability. We study key determinants of environmental and economic development in China to mitigate environmental issues associated with economic growth. We start by discussing the impact of financial inclusion, which has been theoretically and empirically linked to the environment and economy. Easy accessibility to financial services empowers people to capitalize on environmentally friendly initiatives, renewable energy projects, eco-friendly farming practices, etc. Financial inclusion also enables lower-income households to participate in environmental projects with a sense of ownership and contribution for future generations (Wang et al., 2022). The encouraging impressions of financial inclusion on ecological sustainability have been confirmed by Ozili (2023). Financial inclusion is also crucial for economic advancements because consumers can better access savings, loans, and investments. Better access to finance for SMEs results in more capacity building, employment, economic growth, and reduced income inequality (Sethi & Acharya, 2018). However, financial inclusion may also exacerbate environmental issues as better access to finance results in more consumption of products by consumers with an environmental footprint. More loan access might also create corporate demand for natural resources, causing pollution. Jiang and Ma (2019) have empirically confirmed the negative relationship.

An emerging trend in finance worldwide, especially in China, has been the increasing use of technology, i.e., big data, blockchain, AI, and cloud, to provide better financial services. Many Fintech startups have emerged in China, providing financial assistance through digital lending and fundraising, digital payments, Insurtech, Regtech, and more. As per the Cambridge Centre for Alternative Finance, in 2024, 134 Fintech entities are operating in China. Alongside startups, banks in China have been aggressively investing and adopting financial technology to deliver better financial facilities to consumers. Empirically, the influence of Fintech on Chinese economic advancement has been verified in the literature (see, for example, Song & Appiah-Otoo, 2022). Fintech has also been reported to reduce carbon emissions in urban Chinese metropolises (Cheng et al., 2023: Li et al., 2024a)

Green innovation is crucial for sustainability as it focuses on the circular economy, cleaner production, recycling, pollution control, etc., which exerts a dual impact on economic and ecological advancements (Alshammari & Alshammari, 2023). Green products mitigate the adverse effects of environmental deterioration, deforestation, carbon emissions, etc. Eco-friendly manufacturing processes, renewable energy, and green transport systems mitigate environmental degradation and catalyze economic growth by creating new industries and sources of income. Countries that promote green innovation are at the forefront of sustainable economic development, technical advancement, and competitiveness in international markets. Empirically, the mitigating impressions of green innovations on CO_2 emissions in China have been reported by Shan & Shao (2024). Also, Nan et al. (2022) argue that green innovation helps mitigate China's economic growth-led carbon emissions.

Lastly, social sustainability initiatives in education, healthcare, and social safety nets are crucial in shaping a society's well-being and resilience. Better access to education increases a skilled workforce that understands the importance of the environment and economic growth for long-term sustainability. More accessible healthcare and social systems also mitigate the health impacts of climate change, while the marginalized groups are not disproportionately burdened by environmental degradation. Integrating climate considerations into social expenditures is prudent and imperative for fostering a sustainable and equitable future (Zaidi et al., 2021). Social protection programs enhance economic stability and resilience by providing a safety net for vulnerable populations and fostering consumer confidence and spending (Lee & Chang, 2006).

Literature Review

Given its rapid economic growth and industrialization, China faces immense challenges in managing its environmental sustainability. Both environmental and economic sustainability are crucial for China's long-term competitiveness as they impact public health, natural ecosystems, and quality of life (Zhang & Xu, 2021). China has initiated ambitious environmental policies promoting green innovation technologies, ecological conservation, and renewable energy adoption. Policymakers are interested in how technology-based financial products and business models such as Fintech, green innovation, and emerging trends, such as social sustainability, impact economic development and ecological sustainability.

Financial Inclusion, Economic Growth, and Environmental Sustainability

The finance-growth nexus explains that financial inclusion stimulates entrepreneurship, small business development, and investment in physical and human capital, thus fostering job creation and income generation (Beck et al., 2007). Accessibility to financial services such as credits, deposits, insurance, and payments empowers individuals and businesses and directly impacts economic growth. Better access to finance lets individuals and businesses manage their finances well and increase risk-sharing and financial stability. The "Financial Inclusion Development Report 2023", issued by the "People's Bank of China (PBOC)", shows that the number of adults with bank accounts will be nearly 90% in 2022. This higher inclusion reflects the increased ability of individuals and businesses to contribute to economic growth in China, empirically proven by Liu et al. (2021).

However, financial inclusion could have a twofold impact on environmental growth. Studies suggest that financial inclusion can empower people, businesses, and industries to be more resourceful and adopt environmentally sustainable practices (Demirgüç - Kunt et al., 2018). The impressions of financial inclusion on reducing carbon emissions and pollutants have been proved by Shahbaz et al. (2022). Alternatively, more financial inclusion may increase carbon emissions through increased consumption, infrastructure development, and consumer behavior. Empirically, the damaging impressions of financial inclusion have been reported by Le et al. (2020) in the case of Asian economies. Nonetheless, financial inclusion is a vital driver for environmental sustainability and economic growth. The above discussion motivates to develop the following hypotheses:

H1: Financial inclusion enhances economic growth in China

H2: Financial inclusion reduces carbon emissions in China

Fintech, Economic Growth and Environmental Sustainability

China is a leading Fintech hub in the Asia-Pacific; people widely use Fintech-based services for payments, financing, investments, insurance, etc. Several theories may explain the impressions of Fintech on economic development. For example, the Schumpeterian economic growth theory highlights innovation's role and disruption in driving economic growth. Since Fintech disrupts contemporary financial services by offering more efficient, better financial inclusion, it could increase economic growth. The continuous advancement and adoption of FinTech innovation increase economic competitiveness and welfare in developed and developing economies. Similarly, the diffusion of innovation theory explains the speed and pattern through which innovation and technology are adopted and impact economic growth. Empirically, Cevik (2024) has reported the positive impact of Fintech on economic growth in a global setting. Song and Appiah-Otoo (2022) studied this relationship in the context of China and reported an optimistic influence on economic development.

As the environmental economics and Green Finance perspective suggest, Fintech may also influence environmental sustainability. Fintech reduces the need for physical infrastructure and branches, which leads to lower energy consumption and carbon emissions. It could also foster green finance by facilitating the growth and trading of green bonds, carbon credits, and more. The impact of Fintech on carbon emissions reductions in China has been reported by Cheng et al. (2023) and for a global sample by Najaf et al. (2024). However, an alternative perspective is that Fintech may worsen the environment through the rebound effect since improved access to finance may lead to more consumption, financialization, and exploitation of natural resources. Liu et al. (2024) have confirmed the detrimental impression of Fintech on CO_2 emissions in China and Vietnam. The above discussion motivates to develop the following hypotheses:

H3: Fintech enhances economic growth in China

H4: Fintech reduces carbon emissions in China

Social Welfare, Economic Growth, and Environmental Sustainability

Social welfare expenditures in healthcare, education, and social protection programs are crucial for social sustainability. The Human Capital Theory suggests that social expenditures increase economic growth by promoting a healthier, more educated, and more secure workforce. Social capital theory focuses on trust and community bonds generated through social welfare programs, which foster economic collaboration and cooperation among people, increasing economic growth. Furceri and Zdzieicka (2012) have confirmed the positive influence of social spending on economic development. However, Cameraat (2020) explains that the influence of social expenditures on economic sustainability is not uniform and that different types of social spending have different impacts on GDP.

Social protection expenditures can also play a crucial role in buffering vulnerable populations from the adverse effects of climate change, thereby enhancing economic resilience (Graff Zivin et al., 2018). However, social expenditures may exacerbate carbon emissions, as Tebourbi et al. (2022) reported the impact of government education spending on five ASEAN countries. For China, these relationships have not been studied thoroughly. Hence, we propose the following hypotheses:

H5: Social Expenditures enhance economic growth in China

H6: Social Expenditures Reduce carbon emissions in China

Green Innovation, Economic Growth, and Environmental Sustainability

Green Innovation uses technologies to develop processes and products addressing environmental challenges such as carbon emissions, conservation of natural resources, climate change, etc. China has been at the forefront of Green Innovation; in 2023, it commissioned as much solar energy as the world did in 2022, with a growth in wind energy of 66% per year. China contributes over 60% of the new renewable volume, which is estimated to be functional internationally by 2028. Similarly, China is a global leader in electric vehicles (EV), accounting for 50% of global EV sales. Also, China ranks second in the green bonds market, amounting to $ 128 million in 2021. These promising statistics should have implications not only for environmental sustainability but for economic growth as well.

Theoretically, green innovation may accelerate the downward slope of the environmental Kuznets curve (EKC) through technological innovation that reduces carbon emissions. The influence of sustainable innovation on lowering CO_2 emissions in China has been verified by Li et al. (2023) and Liu et al. (2024). However, Dong et al. (2022) performed a similar analysis for developed countries and concluded that the impact is not uniform across all countries. Nonetheless, green innovation impacts economic growth by creating employment opportunities and new business models (Sun et al., 2023). Sustainable innovation is a pivotal driver for environmental sustainability and economic growth, shaping the trajectory toward a more prosperous and sustainable future (Yu et al., 2022: Li et al., 2024b). Hence, we propose the following hypotheses:

H7: Green innovation enhances economic growth in China

H8: Green innovation reduces carbon emissions in China

Data and Methodology

We selected data from China for the years 2014 to 2023. The reason for selecting China has been due to its rapid economic growth and increased carbon emissions. A brief description of variables has been given in Table 1.

Table 1

Variables, Description, Abbreviations, and Sources of Data

Variable Name	Description	Abbreviation	Source
Independent Variables			
Financial Inclusion	Available ATMs per 100,000 adults	FinInc	IMF
Fintech	Growth of Fintech Revenue	Fintech	Statista
Social Expenditures	Public expenditure on social security and employment	SE	Statista
Green Innovation	“Climate change mitigation technologies related to energy generation, transmission, or distribution”	GI	OECD Statistics
Dependent Variables			
Environmental Quality	CO_2 Emissions	CE	Our World in Data
Economic Development	GDP Growth	ED	World Bank

Based on the previous studies of Razzaq et al. (2020) and Kadir et al. (2023), the current study conducts econometric analysis with the application of the following ARDL model for the first Fore Second Dependent Variable, i.e., Economic Development, we replace CE (carbon emissions) with ED (Economic Development) in all 6 Equations.

Dependent variable, i.e., environmental quality proxied by carbon emissions (CE).

$$CE = \nu + \sum_{f=1}^{n} \alpha_f \, CE_{t-f} + \sum_{f=0}^{m1} \beta_f \, FinInc_{t-f} + \sum_{f=0}^{m2} \gamma_f \, Fintech_{t-f} + \sum_{f=0}^{m3} \omega_f \, SE + \sum_{f=0}^{m4} \sigma_f \, GI_{t-f} + z_t \quad (1)$$

Equation 1 specifies $CE - E(F/F - (t-1))$ and F_{t-1} (being the least σ) with z_t which gives rise to {FinInc, Fintech, SE, GI, CE_{t-1}, $FinInc_{t-1}$, $Fintech_{t-1}$, SW_{t-1}, GI_{t-1}, …}. However, the lag order for Schwartz information criteria is indicated with n, m, m_2, m_3, and m_4. Equation 1 establishes that all the variables are presented in logarithmic expressions. The study makes some alterations in the ARDL model (see Equation 1) and thus discusses the QARDL model through Equation 2.

$$Q_{CE} = v(\tau) + \sum_{f=1}^{n} \alpha_f(\tau) CE_{t-f} + \sum_{i=0}^{m1} \beta_f(\tau) FinInc_{t-f} + \sum_{f=0}^{m2} \gamma_f(\tau) Fintech_{t-f} + \sum_{f=0}^{m3} \widehat{w}_f(\tau) SE_{t-f} + \sum_{f=0}^{m4} \sigma_f(\tau) GI_{t-f} + z_t(\tau) \quad (2)$$

In Equation 2, $z_t(\tau)$ = CE - Q_{CE} $(\frac{\tau}{F_{t-1}})$, while τth quantile $(\frac{\tau}{F_{t-1}})$ of CE is dependent on F_{t-1} (for specification, see Kim and White, 2003). Distinct quantiles ranging from 0.05 to 0.95 are employed in the study to infer accurate and precise analysis. Regarding the present moment, the error term possesses a sequential correlation, which is expressed as:

$$Q_{CE} = v(\tau) + \sum_{i=1}^{m_{1-1}} \mho_{FinInc_i}(\tau)\Delta FinInc_{t-1} + \delta_{FinInc}(\tau) FinInc_t + \sum_{i=1}^{m_{2-1}} \mho_{Fintech_i}(\tau)\Delta Fintech_{t-1} + \delta_{Fintech}(\tau) Fintech_t + \sum_{i=1}^{m_{3-1}} \mho_{SE_i}(\tau)\Delta SW_{t-1} + \delta_{SE}(\tau) SW_t + \sum_{i=1}^{m_{4-1}} \mho_{GI_i}(\tau)\Delta GI_{t-1} + \delta_{GI}(\tau) GI_t + z_t(\tau) \quad (3)$$

$$Where\ \delta_{FinInc}(\tau) = \sum_{f=0}^{m1} \beta_f(\tau), \mho_{FinInc_f}(\tau) = -\sum_{i=f+1}^{m1} \beta_j(\tau).$$

$$\delta_{Fintach}(\tau) = \sum_{f=0}^{m1} \gamma_f(\tau), \mho_{Fintech_f}(\tau) = -\sum_{i=f+1}^{m1} \gamma_k(\tau).$$

$$\delta_{SW}(\tau) = \sum_{f=0}^{m1} \widehat{w}_f(\tau), \mho_{SW_f}(\tau) = -\sum_{i=g+1}^{m1} \widehat{w}_k(\tau).$$

$$\delta_{GI}(\tau) = \sum_{f=0}^{m1} \sigma_f(\tau), \mho_{GI_f}(\tau) = -\sum_{i=f+1}^{m1} \sigma_k(\tau).$$

The above-indicated expressions exhibit the dynamics for the shorter run. However, the longer-run connectedness between the independent and dependent variables can be expressed by rearranging Eq. 3:

$$CE = n(\tau) + \acute{X}\beta(\tau) + \varsigma_t(\tau) \quad (4)$$

With X= (FinInc, Fintech, SE, GI) and $\rho_{FinInc}(\tau)$= $\delta_{FinInc}(\tau)\left[1 - \sum_{f=1}^{n} \varphi_{FinInc_k}(\tau)\right]^{-1}$

And

$$E_t = \sum_{g=0}^{\infty} \gamma_{FinInc}(\tau)\Delta FinInc_{t-1} + \sum_{g=0}^{\infty} \sigma_{FinInc_g}(\tau)\Delta\varepsilon_{t-1}, and\ \mu(\tau) = v(\tau)\left[1 - \sum_{k=1}^{n} \varphi_g(\tau)\right] with\ \gamma_g(\tau) = \pi_i(\tau)\rho_{Fintech}(\tau)$$

ρ_{SW} and ρ_{GI} will be calculated on the same line. $\sigma_0(\tau), \sigma_1(\tau), \sigma_2(\tau)$ … … . . and $\pi_0(\tau), \pi_1(\tau)$, … . are defiend such that

$$\left\{\sum_{g=0}^{\infty}\theta_g(\tau) = (1-\sum_{f=0}^{p}\theta_g(\tau)L^f)^{-1} \quad and \quad \sum_{f=0}^{\infty}\pi_f(\tau)L^f = (1-L)^{-1}\left[\frac{\sum_{f=0}^{m1}\beta_f(\tau)L^k}{1-\sum_{f=1}^{m1}\beta_f(\tau)\,L^k} - \frac{\sum_{f=0}^{m1}\beta_f(\tau)}{1-\sum_{f}^{m1}\beta_f(\tau)}\right]\right\}$$

$$Q_{\Delta CE} = v + \rho CE_{t-1} + d'_{FinInc}FinInc_{t-1} + d'_{Fintech}Fintech_{t-1} + d'_{SW}SW_{t-1} + d'_{GI}GI_{t-1} + \sum_{f=0}^{m} d'_f CE_{t-1} + \sum_{f=0}^{n_1-1}\beta_f \Delta FinInc_{t-1} + \sum_{f=0}^{n_2-1}\lambda_f \Delta Fintech_{t-1} + \sum_{k=0}^{n_3-1}\eta_f \Delta SE_{t-1} + \sum_{f=0}^{n_4-1}\sigma_f \Delta GI_{t-1} + z_t \qquad (5)$$

Equation 5 may initiate the contemporary correlation between FinInc, Fintech, SE, and GI, which can be avoided by employing the projection of zt on ΔFinInct, ΔFintecht, ΔSEt, and ΔGIt in the following step: z_t = δFinInc ΔFinInc + δFintech ΔFintech + δSE ΔSE + δGI ΔGI + z'_t. Hence, the concluding form of the "QARDL-ECM model" is quantified via Equation 6.

$$Q_{\Delta CE} = v(\tau) + \c{s}(\tau)CE_{t-1} - \rho_{FinInc}\tau)FinInc_{t-1} - \rho_{Fintech}(\tau)Fintech_{t-1} - \rho_{SW}(\tau)SW_{t-1} - \rho_{GI}(\tau)GI_{t-1} + \sum_{f=1}^{m-1}\sigma_f CE_{t-1} + \sum_{f=0}^{n_1-1}\beta_f \Delta FinInc_{t-1} + \sum_{f=0}^{n_2-1}\gamma_f \Delta Fintech_{t-1} + \sum_{f=0}^{n_3-1}\widehat{w}_f \Delta SW_{t-1} + \sum_{g=0}^{n_4-1}\sigma_g \Delta GI_{t-1} + \cdots + e_t \qquad (6)$$

The impact of past observations of CE on prevailing observations is computed through $a_* = \sum_{k=1}^{m-1} a_k$, however, $\beta_* = \sum_{j=0}^{n_1-1}\beta_j, \lambda\gamma_* = \sum_{f=0}^{n_2-1}\gamma_f, \widehat{w}_* = \sum_{f=0}^{n_3-1}\widehat{w}_f, and\ \sigma_* = \sum_{f=0}^{p_4-1}\sigma_f$ measure the aggregated short-run impact of past and present FinInc, Fintech, SE, and GI levels. Similarly, the cointegrating parameters that are provided in the formulations for FinInc, Fintech, SE, and GI for each variable that is included in the analysis are shown as

$\rho_{FinInc_*} = -\frac{\alpha FinInc}{\c{s}}, \rho_{Fintech} = -\frac{\alpha_{Fintech}}{\c{s}}, \rho_{SW_*} = -\frac{\alpha_{SE}}{\rho\c{s}}$, and $\rho_{GI_*} = -\frac{\alpha_{GI}}{\c{s}}$, respectively. In addition, the study uses the delta method to compute coefficients to ascertain the cointegration among variables in both the short- and long-run. It is vital to note that ρ reflects the element of ECM, which should be statistically significant and negative.

For robustness purposes, the study applies the Wald test, which tests the null and alternative hypotheses for short—and long-run coefficients, i.e., α*, ω*, ρ*, and ş*, by assessing the Chi-square distribution. Granger (1969) first proposes the Grange causality test, used in this study to determine the causal connectedness between the selected variables. Additionally, the analysis has used Trosters (2016) quantile Granger causality approach to provide a clear elucidation and explanation of the causality, which is a crucial step.

Results

Table 2 exhibits the descriptive statistics for the variables used under study. The average number of climate change mitigation patents is 1870.69, registered in China during the sample period. From financial indicators, Fintech has higher average values. Economic development and carbon emission growth go hand in hand. To uncover the number of the time series, we used the JB test, which confers the non-normality of the variables. Skewness and kurtosis values represent the non-normal nature of data series, and such values are appropriate for applying QARDL (Ali et al., 2023; Naseem et al., 2023; Ren et al., 2023). Table 3 shows that variables are spared from the issue of multicollinearity among variables. The negative correlation between carbon emissions and economic development indicates that China has achieved economic development at the cost of environmental deterioration.

Table 2

Summary Statistics

	CE	ED	FinInc	Fintech	SE	GI
Mean	7.334876	7.444781	78.27000	95.10600	10.12430	1870.691

Maximum	8.045740	19.33338	97.04000	296.7100	17.48271	3930.425
Minimum	6.965584	0.797643	46.71000	37.20000	3.676136	650.9742
Std. Dev.	0.332069	5.883418	16.11492	78.77462	3.679029	1188.104
Skewness	1.041640	0.658664	-0.879974	1.835935	0.363143	0.742038
Kurtosis	3.052547	2.562095	2.762796	5.412424	3.245522	2.247545

Table 3

Correlation among Study Variables

	CE	ED	FinInc	Fintech	SE	GI
CE	1					
ED	-0.1291	1				
FinInc	-0.0459	0.1858	1			
Fintech	-0.3634	0.1121	-0.2263	1		
SE	0.3891	0.03975	-0.4713	0.5549	1	
GI	0.8605	0.0498	0.4106	-0.5720	-0.5831	1

Table 4

Outcomes of Unit root test

Variables	ADF (Level)	ADF (Δ)	ZA (Level)	Break Year	ZA (Δ)	Break Year
	I(0)	I(1).	I(0)		I(1).	
CE	-0.637	-7.183***	-1.229	2014	-6.475***	2016
ED	-1.635	-7.093***	-3.683	2017	-7.838***	2018
FinInc	-0.749	-6.610***	-2.284	2018	-6.519***	2022
Fintech	-0.592	-6.017***	-3.119	2021	-6.428***	2021
SE	-0.364	-7.511***	-2.629	2019	-6.185***	2022
GI	-0.821	-6.829***	-3.485	2018	-7.355***	2021

*Note: *** exhibits the level of significance at 1%.*

We employed a Zivot and Andrew structural-break unit root test to identify the order of integration required for applying the QARDL model. All the variables become stationary at first difference I (1), as reported in Table 4. Usually, financial time series exhibit stationarity at first difference (Shahid & Sattar, 2017; Shahid, 2022). The results of the QARDL model are reported in Table 5, where it is evident that ECT is significant and negative, exhibiting a conjunction towards the long-run symmetry.

Table 5

Coefficients of the QARDL model for the short and long-run

Quantiles	Long run						Short run				
	DV: CE (Carbon Emissions used as a proxy to quantity Environmental Quality)										
	$\alpha^*(\tau)$	$\rho^*(\tau)$	$B_{FinInc}(\tau)$	$\beta_{Fintech}(\tau)$	$B_{SE}(\tau)$	$B_{GI}(\tau)$	φ_1CE	ω_0FinInc	ω_1Fintech	λ_0SE	θ_0GI
0.05	0.127	– 0.328	0.199***	0.217*	–0.538***	–0.245**	0.402***	0.212**	0.237***	–0.382***	– 0.208*
0.10	0.130	– 0.291	0.208***	0.240 *	–0.569***	–0.260**	0.430***	0.227**	0.259***	–0.415***	–0.222**
0.20	0.166	– 0.266	0.233**	0.234 *	–0.582***	–0.278***	0.455**	0.242**	0.286***	–0.445***	–0.245**
0.30	0.177	–0.268***	0.262***	0.273 **	–0.596***	–0.285***	0.476**	0.257**	0.425**	–0.468***	–0.269**
0.40	0.179	–0.245***	0.294*	0.302**	–0.616**	–0.302***	0.484**	0.267**	0.445**	–0.502**	–0.286**
0.50	0.182	–0.226***	0.305*	0.314**	–0.636**	–0.345**	0.510***	0.285**	0.576**	–0.516**	–0.335***
0.60	0.199	– 0.239*	0.324***	0.334**	–0.656***	–0.367***	0.513***	0.329***	0.601**	–0.543**	–0.341***
0.70	0.220	– 0.244*	0.351**	0.376***	–0.671***	–0.392***	0.545***	0.359***	0.648**	–0.574***	–0.364***
0.80	0.261	–0.261**	0.368**	0.523***	–0.692***	–0.420***	0.569***	0.382***	0.686**	–0.605***	–0.382***
0.90	0.271	–0.239***	0.388**	0.546**	–0.723***	–0.455***	0.597***	0.418***	0.717*	–0.639***	–0.417***

Quantiles	Long run						Short run				
0.95	0.283	−0.265**	0.417**	0.577***	−0.750***	−0.465***	0.617***	0.454***	0.768**	−0.670***	−0.437***
DV: GDP (used as a proxy to measure Economic Development)											
	$\alpha^*(\tau)$	$\rho^*(\tau)$	$B_{FinInc}(\tau)$	$\beta_{Fintech}(\tau)$	$B_{SE}(\tau)$	$B_{GI}(\tau)$	φGDP	ω_0FinInc	ω_1Fintech	λ_0SE	θ_0GI
0.05	0.127	− 0.328	0.328**	0.301**	0.427***	0.542***	0.538***	0.204**	0.345***	0.230***	0.365**
0.10	0.130	− 0.291	0.346**	0.327 **	0.463***	0.578***	0.560***	0.235* *	0.478***	0.248***	0.380**
0.20	0.166	− 0.266	0.372***	0.346**	0.502***	0.590***	0.581**	0.276***	0.489***	0.275***	0.389***
0.30	0.177	−0.268***	0.389***	0.367**	0.545**	0.601***	0.593**	0.288***	0.517**	0.307***	0.387***
0.40	0.179	−0.245***	0.399***	0.388***	0.571***	0.613***	0.619**	0.297***	0.565***	0.354**	0.405***
0.50	0.182	−0.226***	0.408***	0.410***	0.590***	0.630***	0.630***	0.319***	0.595***	0.399**	0.413***
0.60	0.199	− 0.239*	0.435***	0.434***	0.612**	0.644***	0.655***	0.334**	0.638***	0.432***	0.418***
0.70	0.220	− 0.244*	0.456***	0.478***	0.645***	0.658***	0.679***	0.356***	0.689***	0.443***	0.425***
0.80	0.261	−0.261**	0.477***	0.510***	0.668***	0.671***	0.700***	0.378**	0.718***	0.460***	0.445***
0.90	0.271	−0.239***	0.494***	0.545***	0.681***	0.679***	0.733***	0.415**	0.756***	0.492***	0.467***
0.95	0.283	−0.265**	0.512***	0.587***	0.718***	0.695***	0.761***	0.442***	0.804***	0.521***	0.484***

*Note: ***, ** & *exhibit significance levels at 1%, 5% & 10%.*

All quantiles show a positive association between financial inclusion and carbon emission, which means an increase in financial inclusion in China enhances carbon emissions; hence, financial inclusion deteriorates environmental quality in line with the previous work of Le et al. (2020) and Jiang & Ma (2019). Hence, we reject the H2, which states that financial inclusion reduces carbon emissions. However, we observe a positive association between financial inclusion and GDP growth, thus accepting the H1 and concluding that financial inclusion enhances GDP growth in China, in line with the work of Liu et al. (2021). All the quantiles exhibit positive coefficients for connectedness between Fintech revenues and GDP, indicating that Fintech revenues enhance economic development in China. So H3 is accepted; this finding is in line with the results of Cevik (2024) and Song and Appiah-Otoo (2022). Like financial inclusion, Fintech is positively connected with Carbon emissions, which means that increasing Fintech revenue in China deteriorates the Environmental quality; hence, we reject the H4. Our results align with the work of Liu et al. (2024).

Social welfare expenditures are positively connected with GDP, which aligns with Furceri and Zdzieicka's (2012) previous studies. This finding leads us to accept H5. Further, Social welfare is negatively connected with carbon emissions across all the quantiles; thus, such expenditures reduce carbon emissions and enhance environmental quality. Hence, H_6 is accepted, which states that Social Expenditures Reduce Carbon Emissions, and our findings conform to the earlier work of Graff Zivin et al. (2018). Similarly, we find positive connections between Green environmental change mitigation technologies and GDP growth, indicating that an increase in such innovation enhances economic development. We accept H7 and our finding is in line with (Yu et al., 2022). We find a negative connectedness between green innovation change mitigation technologies and carbon emissions. This means that such green technologies reduce carbon emissions, and the findings are similar to the outcomes of previous studies, e.g., Yii and Geetha (2017) found that green innovation reduces carbon emissions in Malaysia. Niu (2021) observed the same in China, while Ramzan et al., (2023) found similar outcomes from G-11 nations. Hao and Chen (2023) argue that green innovation reduces environmental pollution in E– 7 economies. Hence, we accept H8, which infers that Green Innovation reduces carbon emissions.

We find similar connectedness of all independent variables with both dependent variables in both short and long-run analyses. Moreover, outcomes for the short-run analysis depict those previous values of carbon emissions significantly and positively influence the current values of carbon emissions in all quantiles. It is also evident from the Table that the preceding values of financial inclusion and Fintech positively impact the current values of carbon emissions. However, preceding values of social expenditures and green innovation negatively influence the current values of carbon emissions. On the other hand, previous values of FinInc, Fintech, social welfare, and green innovation positively influence the current values of GDP (Economic Development).

The current study explores parameter consistency by applying the Wald test. Table 6 elaborates on accepting the alternative hypothesis at 1 % for parameter consistency. Contrary to this, the linearity supposition is rejected across discrete tails of each quantile while detecting the long-run parameters of the model. It is clear from the Table that the parameters of the model used in the study have a long-term dynamic pattern. The structural disparity in the study variables indicates that previous values of the indicators are sustained. Table 6 reveals that the alternative hypothesis is accepted in the short run for variables for robustness purposes. Additionally, we observe the nonlinear contemporary influence of all regressors on CO_2 emissions and GDP.

Table 6

Outcomes of Wald test uncovering robustness.

Variables	Wald-statistics (DV: CE)	Wald-statistics (DV: ED)
	Long Run Effects	
ρ	9.844*** (0.000)	13.435*** (0.000)
β_{FinInc}	14.993*** (0.000)	14.002*** (0.000)
$\beta_{Fintech}$	8.834*** (0.000)	10.139*** (0.000)
β_{SE}	5.345** (0.011)	8.512*** (0.011)
β_{GI}	7.9445*** (0.000)	9.001*** (0.000)
φ_1	5.378** (0.013)	8.366*** (0.013)
ω_0	8.206*** (0.000)	9.365*** (0.000)
ω_1	4.384** (0.0294)	7.430*** (0.0294)
λ_0	6.932*** (0.000)	8.366*** (0.000)
θ_0	6.394*** (0.000)	7.103*** (0.000)
θ_1	5.273*** (0.000)	7.636*** (0.000)
δ_0	6.888*** (0.000)	9.301*** (0.000)
δ_1	7.347*** (0.000)	8.732*** (0.000)
Short Run effects		
ω^*	12.384*** (0.000)	13.997*** (0.000)
θ^*	13.834*** (0.000)	14.737*** (0.000)
δ^*	16.837*** (0.000)	17.830*** (0.000)

The study further employs the Granger causality quantile test to assess the directions of relationships between variables. Table 7 clearly shows that FinInc, Fintech, and SE (Social Welfare) have unidirectional causality with carbon emissions, while GI (green innovation) has bidirectional causality. On the other hand, all the independent variables have bidirectional causality with GDP.

Table 7

Outcomes of Granger causality quantile test.

Quantiles			[0.05–0.95]	0.05	0.1	0.2	0.3	0.3	0.5	0.6	0.7	0.8	0.9	0.95
			DV: CE (Carbon Emissions)											
ΔCE_t	→	$\Delta FinInc_t$	0.530	0.683	0.831	0.736	0.193	0.584	0.382	0.536	0.395	0.653	0.359	0.485
$\Delta FinInc_t$	→	ΔCE_t	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ΔCE_t	→	$\Delta Fintech_t$	0.481	0.485	0194	0480	0.395	0488	0.299	0.664	0.495	0.754	0.621	0.359
$\Delta Fintech_t$	→	ΔCE_t	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ΔCE_t	→	ΔSE_t	0.609	0.847	0.649	0.112	0.653	0564	0773	0.876	0.391	0.442	0.562	0.832
ΔSE_t	→	ΔCE_t	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ΔCE_t	→	ΔGI_t	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000
ΔGI_t	→	ΔCE_t	0.001	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000
			DV: Economic Development (GDP Growth)											
ΔGDP_t	→	$\Delta FinInc_t$	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.005
$\Delta FinInc_t$	→	ΔGDP_t	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.004	0.000	0.000	0.000	0.000
ΔGDP_t	→	$\Delta Fintech_t$	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000
$\Delta Fintech_t$	→	ΔGDP_t	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000
ΔGDP_t	→	ΔSE_t	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
ΔSE_t	→	ΔGDP_t	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ΔGDP_t	→	ΔGI_t	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.006	0.000	0.005	0.000	0.001
ΔGI_t	→	ΔGDP_t	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000

Conclusions, Policy Implication, and Recommendations

The study investigates the connection between financial inclusion, fintech, social welfare, green technological innovation, and environmental quality and economic development. Instead of using the traditional ARDL model, the study employs the QARDL model to assess the connectedness across different quantiles. As described in the methodology section, we find that ECM values are negative and significant across all quantiles, indicating convergence of long-run equilibrium for dependent and independent variables. Financial Inclusion and Fintech deteriorate the environmental quality while social welfare and green innovation enhance it. Moreover, we observe that all the independent variables enhance economic development. Moreover, the study observes unidirectional causality between FinInc, Fintech, and SE toward Carbon emissions, while bidirectional causality exists between GI and Carbon emissions. On the other hand, bidirectional causality is observed between FinInc, Fintech, SE, and GI towards economic development.

The findings suggest that China should promote Financial Inclusion and the development of Fintech for economic growth. At the same time, it should also ensure the use of green/clean energy in Fintech and optimize financial inclusion and Fintech to avoid environmental deterioration. China should implement reforms to grow financial inclusion and Fintech. The government should apply a threshold on Fintech payments to avoid climate deterioration and enhance GDP. The Government should introduce more green innovation, promote the consumption of renewable energies, and promote the manufacturing of eco-friendly technologies to enhance economic and environmental growth. Moreover, the Chinese Government should invest more in social development or welfare; such investments could enhance human capital and environmentally conscious behavior.

The study has limitations; it is restricted to a single country; scholars and scholars should conduct the same study on multiple economies, such as Asia, Africa, BRICS, the E-7, N-11, and G-10, in the future. The researchers may also use other economic variables, such as Financial Development, Green Finance, government intervention, and institutional quality. Furthermore, the study employs the QARDL model. However, we suggest that researchers apply the asymmetric ARDL model to validate the results obtained in the current study. Future researchers should use different proxies to measure the variables used in the current study.

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