Revealing the effectiveness of green technological progress and financial innovation on green economic growth: the role of environmental regulation

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Abstract

Green economic growth is the best alternative strategy for sustainable development. Existing literature investigated the determinants of green economic growth in China and provides mixed results. Thus, our study explores the impact of green environmental technology, financial innovation, and environmental regulations on green economic growth by controlling the impact of renewable energy consumption, trade, and education. The study explores the symmetric and asymmetric associations by employing ARDL and NARDL approaches. The ARDL long-run findings display that green environmental technologies, environmental regulations, and financial innovations positively and significantly contribute to green economic growth. However, the NARDL long-run findings infer that positive shock in green environmental technology, financial innovation, and environmental regulation exerts a significant and positive impact on green growth, while negative shock in green environmental technology, financial innovation, and environmental regulation have an insignificant impact on green growth. Based on the findings, the study delivers important policy implications to promote green economic growth in China.

Introduction

Economies of the world are now keen to shift their economic structures and industries to green growth. Green growth refers to the innovation of green technologies for cleaner production, which is considered an important driver of green economic growth (Mensah et al., 2019). Green growth also refers to a plausible approach for CO2 emissions reduction and energy saving and is considered a solution measure to control the environmental deterioration (Sandberg et al., 2019). Green growth mainly relies on technological innovation that improves the efficiency of production (UNEP, 2011). Productivity growth is not possible without technological advancement. Technological innovation is vital, but resource income growth is still passive in its momentum. Technology has been given an exogenous chance in the growth theories for a long time (Solow, 1956). On the other side of ideas, endogenous growth has been considered an endogenous element and given a significant status of modifying the development (Romer, 1990). In the fourth industrial revolution, the role of technology was important (Ullah et al. 2021). All these advanced technologies modified growth through productive transmission (Umar et al., 2021). The concept of the fourth industrial revolution noted that eco-friendly technologies developments have helped to repair and improve the environmental issues on a better scale. The growth of green played a significant role in adjusting the economic dimensions according to the level of technological development. Indeed, this development of technologies has had a depleting impact on pollution (Chen et al. 2022). Besides this government is encouraging to replacement of non-renewable resources with sustainable energy resources without damaging the economic growth.

Indeed, financial innovation is enormous attainment for green economic growth and technological and scientific progress. Financial innovation brings technology innovation to the economy that produces new business applications, models, products or processes that exert significant influence on financial institutions and financial markets with significant increases in the performance of financial services (Liu et al. 2022). Scholars believe that vision, strategies, rules, value-added, and participants are the major determinants that can change the financial market (Hung and Luo, 2016). Financial innovation is considered a wider extension of the financial ecosystem that contains innovations in credit markets, payment systems, and insurance. The present literature focuses on the effect of financial technology innovation on green growth (Zhang et al., 2021; Zhou et al. 2022). Currently, the level of financial innovation is constantly rising throughout the world. This increase in financial innovation affects the operation and production capacity of organizations by altering the financial positions through financial provision, thus influencing the economy and environment (Cao et al., 2021).

To protect the environment and attain green economic growth, the governments and policymakers adopt environmental regulation policies. It is believed that environmental regulation policies influence production decisions such as innovation incentives, capital investment, and resource allocation. Environmental regulation policies increase the cost of producing pollution emissions, hence encouraging innovations that aim to enhance product quality and reduce the cost of production which ultimately enhance product efficiency and value (Porter and Van der Linde, 1995). Thus, the environmental regulation policies directly and indirectly influence economic performance and environmental outcomes (Wang et al. 2019). Green economic growth and green productivity development are part of the emerging debate among policymakers, environmentalists, and development economists (Shen et al., 2017). Hence, to explore the effect of environmental regulation policies on green economic growth is important to provide new empirical evidence. Moreover, understanding the transmission channel of environment regulation policies on green economic growth is vital for the choice and design of environmental policies for policymakers and governments.

Although a bulk of literature is available exploring the effect of financial innovation on economic development. However, very limited research is done on exploring the effect of financial innovation on green economic growth. Additionally, the empirical research focusing on the impact of environmental regulations on green economic growth is found to be inconclusive (Zhao et al. 2022). Innovation in technology can encourage green growth. The link of international trade among economies affects green growth in three important ways; such as composition effect, scale effect, and technique effect (Danish and Ulucak, 2020). In technique effect, international trade can be beneficial, if it uses eco-friendly and efficient technologies which help to reduce the carbon emission and, as a result, improve green growth. International trade usually causes to boost economic activities, which also increase in consumption of fossil fuel and finally increase the carbon emission which is the scale effect. Many studies on influential factors successfully gain the attention of researchers and policymakers in this regard. All past studies have applied the traditional time series and panel methods of estimation. However, the study has applied an advanced estimation approach to observe the matter under consideration.

Furthermore, this study gives a new idea of the role of technological progress, financial innovation, and environmental regulation in green growth. Hence, the present study aims to explore the effectiveness of green technological progress, financial innovation, and environmental regulation on green economic growth in China over the time horizon 1993–2020. The study contributes in the following manners. Firstly, no study is available, particularly examining the role of green technological progress on green economic growth. Secondly, the study proposes the path and influential mechanism of the effect of financial innovation on green economic growth. Thirdly, the study measures the impact of environmental regulation on green economic growth. Lastly, the study will help development economists and environmentalists in adopting relevant policy implications that foster significant green economic growth.

Theoretical Framework, Model, And Methods

There is a consensus among economic theorists that investment in research and development activities, technological development, and a continuous innovation process is crucial to spur economic growth. In this era of modernization, the changing economic situation requires that innovative activities must also flourish at a great pace. In such a dynamic economic environment, innovations are considered the main catalyst to fulfill the demand for every economic sector. Solow (1956) highlighted the link between innovation and economic growth in the finance literature. Similarly, Schumpeter (1911) also shed light on the possible connection between innovation and economic growth, particularly the role of technological advancement in the economy. All the scientific, financial, technological, and commercial activities essential in refining and developing new products and services in the economy fall under the purview of innovations (Jänicke, 2012). Any innovation that can increase the efficiency of the financial system, promote the information channels, and improve the payment mechanisms is known as financial innovation (Zhang et al. 2021). In addition to the development of financial markets and technologies, the eruption of financial instruments and the efficient distribution of capital are the reasons behind financial innovation, which spur economic growth. In light of the above arguments, we deduce that technological and financial innovations also help promote green growth. In the light of the above arguments, we have constructed the following long-run model.

$$\mathrm{GG_t} = \rho_0 + \rho_1\mathrm{GET_t} + \rho_2\mathrm{FI_t} + \rho_3\mathrm{ER_t} + \rho_4\mathrm{REC_t} + \rho_5\mathrm{Education_t} + \epsilon_t(1)$$

Where green growth is a function of green environmental technology (GET), financial innovation (FI), environmental regulation (ER), renewable energy consumption (REC), school enrolment tertiary (Education), and random error term (ϵ_t). The analysis is not limited to the long-run estimates only; hence, the above long-run equation is re-specified in the form of an error correction format given below:

$$\begin{aligned}\Delta\mathrm{GG_t} = {} & \beta_0 + \sum_{k=1}^{n}\beta_{1k}\Delta\mathrm{GG}_{t-k} + \sum_{k=0}^{n}\beta_{2k}\,\Delta\mathrm{GET}_{t-k} + \sum_{k=0}^{n}\beta_{3k}\,\Delta\mathrm{FI}_{t-k} + \sum_{k=0}^{n}\beta_{4k}\,\mathrm{ER}_{t-k} + \sum_{k=0}^{n}\beta_{5k}\,\mathrm{REC}_{t-k} \\ & + \sum_{k=0}^{n}\beta_{6k}\,\mathrm{Education}_{t-k} + \rho_1\mathrm{GG}_{t-1} + \rho_2\mathrm{GET}_{t-1} + \rho_3\mathrm{FI}_{t-1} + \rho_4\mathrm{ER}_{t-1} + \rho_5\mathrm{REC}_{t-1} \\ & + \rho_6\mathrm{Education}_{t-1} + \varepsilon_t \qquad (2)\end{aligned}$$

Equation (2) can simultaneously produce short and long-run estimates, known as the ARDL model of Pesaran et al. (2001). In Eq. (2), we can get the short-run estimates from the first-differenced variables and the long-run estimates from the $\rho_2 - \rho_5$normalized on ρ_1. Pesaran et al. (2001) introduce the bounds F-test to check the co-integration among the long-run variables. While all other time series techniques such as Engle and Granger (1987) and Johansen and Juselius (1990) only work if the variables are stationary after differencing once, the ARDL model can work efficiently even if some of the variables are stationary at the level and other are stationary at first difference. Another advantage of the ARDL method is its efficient performance in the case of a small sample size. Since it adds a short-run dynamic process, it is a superior technique because of its power to deal with endogeneity and serial correlation (Pesaran et al. 2001). However, asymmetric analysis is the primary focus of the analysis; therefore, we use the partial sum technique of Shin et al. (2014) and divide the variables such as GET, FI, and ER into their positive and negative components.

$$GET^{+}_{t} = \sum_{n=1}^{t} \Delta GET^{+}_{t} = \sum_{n=1}^{t} \max(\Delta GET^{+}_{t}, 0) \quad (3a)$$

$$GET^{-}_{t} = \sum_{n=1}^{t} \Delta GET^{-}_{t} = \sum_{n=1}^{t} \min(\Delta GET^{-}_{t}, 0) \quad (3b)$$

$$FI^{+}_{t} = \sum_{n=1}^{t} \Delta FI^{+}_{t} = \sum_{n=1}^{t} \max(\Delta FI^{+}_{t}, 0) \quad (3c)$$

$$FI^{-}_{t} = \sum_{n=1}^{t} \Delta FI^{-}_{t} = \sum_{n=1}^{t} \min(\Delta FI^{-}_{t}, 0) \quad (3d)$$

$$ER^{+}_{t} = \sum_{n=1}^{t} \Delta ER^{+}_{t} = \sum_{n=1}^{t} \max(\Delta ER^{+}_{t}, 0) \quad (3e)$$

$$ER^{-}_{t} = \sum_{n=1}^{t} \Delta ER^{-}_{t} = \sum_{n=1}^{t} \min(\Delta ER^{-}_{t}, 0) \quad (3f)$$

The positive series are given in equations 3a, 3c, and 3e, whereas the negative series are shown in equations 3b, 3d, and 3f. Replacing these partial sum variables in place of the original variables in Eq. (2) will make it the NARDL model of shin et al. (2014), as shown below:

$$\begin{aligned}
\Delta GG_t = {} & \beta_0 + \sum_{k=1}^{n} \beta_{1k} \Delta GG_{t-k} + \sum_{k=0}^{n} \beta_{2k} \Delta GET^{+}{}_{t-k} + \sum_{k=0}^{n} \beta_{3k} \Delta GET^{-}{}_{t-k} + \sum_{k=0}^{n} \beta_{4k} \Delta FI^{+}{}_{t-k} + \sum_{k=0}^{n} \beta_{5k} \Delta FI^{-}{}_{t-k} \\
& + \sum_{k=0}^{n} \beta_{6k} \Delta ER^{+}{}_{t-k} + \sum_{k=0}^{n} \beta_{7k} \Delta ER^{-}{}_{t-k} + \sum_{k=0}^{n} \beta_{8k} \Delta REC_{t-k} + \sum_{k=0}^{n} \beta_{9k} \text{Education}_{t-k} \\
& + \rho_1 GG_{t-1} + \rho_2 GET^{+}{}_{t-1} + \rho_3 GET^{-}{}_{t-1} + \rho_4 FI^{+}{}_{t-1} + \rho_5 FI^{-}{}_{t-1} + \rho_6 ER^{+}{}_{t-1} + \rho_7 ER^{-}{}_{t-1} \\
& + \rho_8 REC_{t-1} + \rho_9 \text{Education}_{t-1} + \varepsilon_t \qquad (4)
\end{aligned}$$

Equation (4) is a non-linear model, which is an advanced form of Eq. (2). Shin et al. (2014) suggested that a non-linear model does not need any special treatment and can be dealt with the same estimation technique and tests as the linear model. However, the short and long-run Wald asymmetric tests are to be conducted before concluding whether the effects of the GET, FI, and ER on green growth are symmetric or not. To prove asymmetry in the short run, we need to confirm that the sum of estimates attached to ΔGET^{+}, ΔFI^{+}, and ΔER^{+} are different from the estimates connected to ΔGET^{-}, ΔFI^{-}, and ΔER^{-}. Similarly, the difference between the estimates of GET^{+}, FI^{+}, and ER^{+} and ΔGET^{-}, ΔFI^{-}, and ΔER^{-} confirms the long-run asymmetric impacts of these variables.

Data

The dependent variable used in the analysis is green growth, measured through environmentally adjusted multifactor productivity. Among the independent variables, green environmental technology is calculated through environment-related technologies as a % of total technologies. Similarly, financial innovation is measured by research and development expenditure as a % of GDP. Environmental-related taxes as a % of total revenues are used as a proxy for environmental regulations. Renewable energy consumption is proxied through total energy consumption from nuclear, renewables, and others in quad BTU. Finally, education is measured through School enrollment, tertiary as a % of the total. The data on green growth, green environmental technology, financial innovation, and environmental regulations are obtained from OECD, the data on renewable energy consumption is obtained from energy information administration (EIA), and the data on education is gathered from world development indicator (WDI). The detailed data description and definition of the variables are provided in Table 1.

Table 1
Definitions and data description

Variables	Definitions	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	Probability
GG	Environmentally adjusted multifactor productivity growth	9.181	8.673	13.13	7.103	1.570	1.292	3.823	8.273	0.016
GET	Environment-related technology, % of all technologies	9.795	9.847	11.99	7.387	1.508	-0.059	1.676	1.987	0.370
FI	Research and development expenditure (% of GDP)	1.339	1.369	2.192	0.299	0.618	-0.139	1.673	2.068	0.356
ER	Environmentally related taxes, % total tax revenue	3.225	2.980	6.360	0.200	1.763	0.189	2.053	1.170	0.557
REC	Total energy consumption from nuclear, renewables, and other (quad Btu)	7.153	4.457	21.02	1.508	6.078	0.930	2.563	4.110	0.128
Trade	Trade (% of GDP)	44.17	39.46	64.47	32.42	10.04	0.709	2.202	2.978	0.226
Education	School enrollment, tertiary (% gross)	22.23	20.21	53.76	2.890	16.42	0.615	2.112	2.591	0.274

Results And Discussion

The findings of the DF-GLS unit root test and PP unit root test in Table 2 revealed that none of the series is integrated at the second difference in the model. The dependent variable, green economic growth is integrated at the first difference in both unit root tests. The independent variables and control variables are either integrated at level or first difference. These results confirmed the possibility of exploring the linear and non-linear associations among the variables by using ARDL and NARDL approaches. Table 3 provides the resultant output of the BDS test. The coefficient estimates of the BDS test confirm the non-linear association among variables in the models. The long-run and short-run coefficient estimates of the linear ARDL model are reported in Table 4. While the long-run and short-run coefficient estimates of the non-linear NARDL model are reported in Table 5. Based on three focused variables, we have regressed three separate regressions. Green environment technology is treated as a focused variable in model 1, financial innovation in model 2, and environmental regulation in model 3.

Table 2
Unit root testing

	DF-GLS		PP			
	I(0)	I(1)	I(0)	I(1)	DF-GLS	PP
GG	-1.022	-2.098**	-0.321	-3.125**	I(1)	I(1)
GET	-1.654*		-1.231	-2.658*	I(0)	I(1)
FI	-0.378	-4.564***	-1.954	-4.654**	I(1)	I(1)
ER	-1.145	-1.924*	-1.758	-3.965***	I(1)	I(1)
REC	-2.135**		-2.654*		I(0)	I(0)
Trade	-1.475	-3.875***	-1.345	-3.425**	I(1)	I(1)
Education	0.254	-2.835***	1.425	-2.865*	I(1)	I(1)
Note: *p < 0.1; **p < 0.05; and ***p < 0.01						

Table 3
BDS test

	GET			FI			ER		
Dimension	BDS Statistic	Std. Error	z-Stat	BDS Statistic	Std. Error	z-Stat	BDS Statistic	Std. Error	z-Stat
2	0.195	0.008	23.95	0.195	0.008	23.10	0.175	0.009	18.85
3	0.324	0.013	24.43	0.326	0.014	23.61	0.291	0.015	19.34
4	0.408	0.016	25.17	0.413	0.017	24.37	0.360	0.018	19.60
5	0.463	0.017	26.69	0.476	0.018	26.13	0.396	0.020	20.26
6	0.505	0.017	29.40	0.516	0.018	28.53	0.409	0.019	21.16
Note: *p < 0.1; **p < 0.05; and ***p < 0.01									

As described in Table 4, green environmental technology is positively correlated with green economic growth in the long-run at 1 percent level of significance. It displays that a 1 percent upsurge in green environmental technology boosts green economic growth by 2.749 percent in the long-run. Findings further describe that financial innovation is positively correlated with green economic growth in the long-run at 1 percent level of significance. It demonstrates that a 1 percent upsurge in financial innovation lifts green economic growth by 3.189 percent in the long-run. Moreover, environmental regulations are positively associated with green economic growth in the long-run at 1 percent level of significance. It shows that a 1 percent increase in implementation of environmental regulations raises green economic growth by 0.674 percent in the long-run. In short, findings display that green environmental technology, financial innovation, and environmental regulation are significant drivers of green economic growth in China. The coefficient estimates of control variables illustrate that renewable energy consumption and trade are positively associated with green economic growth in the long-run in all three models.

However, education reports no impact on green economic growth in the long-run as the coefficient estimates are statistically insignificant in all three models. The short-run findings illustrate that green environmental technology, financial innovation, and environmental regulation report no impact on green economic growth as confirmed by statistically insignificant coefficient estimates of all three variables. However, renewable energy consumption and trade are positively linked with green economic growth in the short-run. But the impact of education on green economic growth is again statistically insignificant in the short-run.

Table 4
ARDL estimates of green economic growth

	Model-1		Model-2		Model-3	
Variable	**Coefficient**	**t-Stat**	**Coefficient**	**t-Stat**	**Coefficient**	**t-Stat**
Short-run						
GET	2.301	0.782				
GET(-1)	3.003	1.479				
FI			2.797	1.449		
FI(-1)			1.026**	2.478		
ER					0.132	0.323
ER(-1)					0.484	1.224
REC	2.058***	3.199	1.938***	3.481	1.959***	3.011
REC(-1)	1.552***	2.652	1.221***	2.583	1.250**	1.972
REC(-2)	1.558**	2.130	1.145*	1.823	1.178	1.342
TRADE	0.126**	2.670	0.043	1.003	0.111**	2.303
TRADE(-1)	-0.030	0.454	-0.022	0.359	-0.054	0.836
TRADE(-2)	0.159***	3.463	0.110**	2.519	0.159***	3.064
EDUCATION	0.108	1.023	0.111	1.503	0.055	0.647
EDUCATION(-1)	0.130	1.056				
Long-run						
GET	2.749***	4.040				
FI			3.189***	3.530		
ER					0.674***	3.233
REC	1.071***	2.955	0.476**	2.273	0.514**	2.125
TRADE	0.259***	5.888	0.195***	6.450	0.236***	5.541
EDUCATION	0.022	0.222	0.123	1.302	0.060	0.685
C	19.55***	4.600	3.201***	2.370	1.128	0.836
Diagnostics						
F-test	6.154***		8.235***		6.354***	
ECM(-1)*	-0.583***	7.143	-0.646***	8.270	-0.554***	7.190
LM	1.256		0.955		1.278	
RESET	0.654		0.147		1.156	
CUSUM	S		S		S	
CUSUM-sq	S		S		S	

Note: *p < 0.1; **p < 0.05; and ***p < 0.01

Table 5 illustrates the short-run and long-run findings of NARDL models. It reveals that positive shock in green environmental technology is positively associated with green economic growth while negative shock in green environmental technology have no significant effect on green economic growth in the long-run. The findings display that 1 percent upsurge in positive shock of green environmental technology boosts green economic growth by 1.962 percent in the long-run. Our study suggests a positive linkage between green environmental technology and green economic growth. These findings are supported by Mensah et al. (2019) and Danish & Ulucak (2020). Mensah et al.

(2019) denoted that green environmental technology stimulates green economic growth. Additionally, Danish & Ulucak (2020) denoted that technology innovation is an imperative determinant that enhances energy efficiency and controls energy consumption. Thus, to support green economic growth, eco-innovation and green environmental technology are important especially for mitigating CO_2 emissions and promoting energy conservation. In short, green environmental technology encourages cleaner production, hence promoting green economic growth.

The results also display that positive shock in financial innovation is positively correlated with green economic growth in the long-run; however, negative shock in financial innovation reports insignificant impact on green economic growth in the long-run. It demonstrates that a 1 percent upsurge in positive shock of financial innovation uplifts green economic growth by 2.076 percent in the long-run. This finding is also backed by Zhang et al. (2021) and Zhou et al. (2022). Financial innovation is positively associated with green economic growth, which suggests that financial innovation improves the efficiency of resource allocation and provides new prospects for green technology innovation. Our findings suggest that financial innovation stimulates green technology innovation in the industrial sector that enhances green economic growth. Financial innovation stimulates green growth via green investment and green credit. Finding infers that financial innovation enhances the efficiency of the industrial sector in gaining credit market information and enables them to screen information about borrowers, thus reducing fluctuations in the economy.

Moreover, a positive shock in environmental regulations is positively associated with green economic growth in the long-run but the negative shock in environmental regulations has no impact on green economic growth in the long-run. It shows that a 1 percent increase in positive shock of environmental regulations raises green economic growth by 1.021 percent in the long-run. Our findings report the positive impact of environmental regulations on green economic growth. It infers that environmental regulations directly influence production-related decisions of firms such as innovation incentives, capital investment, and resource allocation. Hence, the positive association between environmental regulation and green economic growth provides supporting evidence for the Porter hypothesis. This result is backed by Porter's hypothesis. Porter & Van der Linde (1995) noted that environmental regulations encourage new innovations that result in increasing overall productivity. These findings are supported by Wang and Shen (2016), who reported an asymmetric association between environmental regulations and green economic growth. The understanding of the nexus between environmental regulations and green economic growth is vital for the choice and design of government environmental policies.

The findings of control variables describe that renewable energy consumption and trade exert a significant and positive influence on green economic growth in all three models in the long-run. However, education reports an insignificant impact on green economic growth in the long-run in all three models. In the short-run, findings describe that positive and negative shock in green environmental technology report an insignificant impact on green economic growth in the short run. In contrast, positive shock in financial innovation and environmental regulation report a significant positive impact on green economic growth in the short-run. But the negative shock in financial innovation and environmental regulations report an insignificant impact on green economic growth in the short-run. Renewable energy consumption and trade report a significantly positive influence on green economic growth in the short-run. However, the impact of education is found statistically insignificant on green economic growth in the short-run. In the end, the coefficient estimates of all diagnostic tests validate the findings of ARDL and NARDL models.

Table 5
NARDL estimates of green economic growth

	Model-1		Model-2		Model-3	
Variable	**Coefficient**	**t-Stat**	**Coefficient**	**t-Stat**	**Coefficient**	**t-Stat**
Short-run						
GET_POS	1.047	0.864				
GET_POS(-1)	0.831	1.308				
GET_NEG	0.251	0.066				
GET_NEG(-1)	0.175	0.302				
FI_POS			1.975**	2.057		
FI_POS(-1)			1.289***	2.889		
FI_NEG			0.484	0.755		
FI_NEG(-1)			0.876	1.549		
ER_POS					1.142**	2.503
ER_NEG					0.129	0.231
REC	1.234***	3.043	1.191***	4.052	1.214**	2.427
REC(-1)	1.231**	2.436	1.400***	3.015	1.299**	2.063
REC(-2)	1.647**	2.103	1.329**	2.072	0.972	1.054
TRADE	0.086**	1.982	0.049	1.159	0.069	1.303
TRADE(-1)	0.018	0.203	0.035	0.568	0.038	0.559
TRADE(-2)	0.171	1.561	0.117***	2.786	0.195***	3.439
EDUCATION	0.055	0.536	0.077	1.093	0.005	0.048
Long-run						
GET_POS	1.962***	3.859				
GET_NEG	0.679	0.427				
FI_POS			2.076***	2.948		
FI_NEG			1.285	0.473		
ER_POS					1.021***	3.258
ER_NEG					0.115	0.234
REC	0.806***	3.697	0.497***	3.037	0.498**	2.492
TRADE	0.194***	6.193	0.185***	7.231	0.202***	5.203
EDUCATION	0.039	0.609	0.071	0.982	0.004	0.048
C	1.753	1.540	2.136*	1.765	2.792*	1.935
Diagnostics						
F-test	9.254***		7.985***		5.456***	
ECM(-1)*	-0.418***	10.37	-0.584***	9.406	-0.619***	7.471
LM	1.253		0.365		1.658	
RESET	0.654		1.025		0.987	

Note: *p < 0.1; **p < 0.05; and ***p < 0.01

	Model-1	Model-2	Model-3
CUSUM	S	S	S
CUSUM-sq	S	S	S
Wald-LR	4.988***	6.987***	5.689***
Wald-SR	1.023	5.620***	0.365
Note: *p < 0.1; **p < 0.05; and ***p < 0.01			

Conclusion And Implications

Financial development serves as a catalyst in the economic development of emerging and developed economies. In this regard, innovations are crucial in the financial sector to meet the growing need of the current economic environment where demand fluctuates quickly. On the other side, technological innovations also have a crucial role in the economic development of the nation. Investing heavily in research and development activities and initiating technological innovations programs may lead the economy towards the path of sustained economic growth. Environmental sustainability has gained paramount importance in recent times and has come into the limelight at all international forums. As a result, policymakers are striving to find a way how to protect the environment for current and future generations without compromising economic growth. One important factor that grabbed the attention of policymakers and empirics is green growth, which refers to the complete decoupling of economic growth and CO2 emissions. In this analysis, our motive is to find the asymmetric determinants of green growth, including financial innovations, green technological development, and related environmental regulations.

Empirical analysis of the study starts with applying unit root tests, confirming that the series included in the analysis are either I(0) or I(1). The results of unit root tests induce us to apply the ARDL model. Since asymmetric analysis is our primary objective; hence, we have also applied the BDS test, allowing us to employ the non-linear model. The long-run linear estimates of GET, FI, and ER are significantly positive, implying that green technological progress, financial innovation, and environmental regulations positively impact green economic growth. Similarly, the long-run estimates attached to GET_POS, FI_POS, and ER_POS are positive and significant and the estimates attached to GET_NEG, FI_NEG, and ER_NEG are insignificant. These results suggest that the positive change in the GET, FI, and ER help increase the green growth while the negative change in all these variables does not have any noticeable impact on the green growth. In general, our findings confirm that a positive change in green technological progress, financial innovation, and environmental regulations are beneficial in achieving green growth. Our results also confirm the asymmetric impact of these factors on green growth, and the estimates of the WALD test are also significant, which is a testimony of the asymmetric effects.

In the light of the above findings, our study has some policy implications for the concerned stakeholders. First of all, the results clearly indicate that the effects of green technological progress, financial innovation, and environmental regulations on green growth are asymmetric. Therefore, the policymakers should consider positive and negative shocks in the concerned variables while devising the policies to achieve green growth. Secondly, the policymakers should focus on the innovations in the financial sector, such as the development of financial markets, the progress in information technologies, the evolution of financial instruments, and making the mechanism of capital distribution more efficient and inexpensive. This development in the financial sector promotes the green factor productivity in the economy. Thirdly, the policymakers should encourage the research and development-related activities that are crucial for making environmental-related technological progress. Fourthly, the environmental regulations must complement other policies to achieve green growth. However, the implementation of environmental taxes should apply with great caution because that may increase the cost of the products and negatively impact the firm’s competitive position.

Declarations

Ethical Approval: Not applicable

Consent to Participate: I am free to contact any of the people involved in the research to seek further clarification and information

Consent to Publish: Not applicable

Authors Contributions: This idea was given by Ying Su. Ying Su and Xinwei Gao wrote the complete paper. Xinwei Gao read and approved the final version.

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References

1. Cao J, Law SH, Samad ARBA, Mohamad WNBW, Wang J, Yang X (2021) Impact of financial development and technological innovation on the volatility of green growth—evidence from China. Environ Sci Pollut Res 28(35):48053–48069
2. Chen J, Rojniruttikul N, Kun LY, Ullah S (2022) Management of Green Economic Infrastructure and Environmental Sustainability in One Belt and Road Enitiative Economies.Environmental Science and Pollution Research,1–11
3. Danish, Ulucak R (2020) How do environmental technologies affect green growth? Evidence from BRICS economies. Sci Total Environ 712:136504
4. Engle RF, Granger CW (1987) Co-integration and error correction: representation, estimation, and testing.Econometrica: journal of the Econometric Society,251–276
5. Hao LN, Umar M, Khan Z, Ali W (2021) Green growth and low carbon emission in G7 countries: how critical the network of environmental taxes, renewable energy and human capital is? Sci Total Environ 752:141853
6. Jänicke M (2012) "Green growth": From a growing eco-industry to economic sustainability. Energy policy 48:13–21
7. Johansen S, Juselius K (1990) Maximum likelihood estimation and inference on cointegration—with appucations to the demand for money. Oxf Bull Econ Stat 52(2):169–210
8. Liu D, Zhang Y, Hafeez M, Ullah S (2022) Financial inclusion and its influence on economic-environmental performance: demand and supply perspectives.Environmental Science and Pollution Research,1–10
9. Mensah CN, Long X, Dauda L, Boamah KB, Salman M, Appiah-Twum F, Tachie AK (2019) Technological innovation and green growth in the Organization for Economic Cooperation and Development economies. J Clean Prod 240:118204
10. Pesaran MH, Shin Y, Smith RJ (2001) Bounds testing approaches to the analysis of level relationships. J Appl Econom 16(3):289–326
11. Porter ME, Van der Linde C (1995) Toward a new conception of the environment-competitiveness relationship. J economic Perspect 9(4):97–118
12. Romer PM (1990) Endogenous technological change. *Journal of political Economy*, *98*(5, Part 2), S71-S102
13. Sandberg M, Klockars K, Wilén K (2019) Green growth or degrowth? Assessing the normative justifications for environmental sustainability and economic growth through critical social theory. J Clean Prod 206:133–141
14. Shin Y, Yu B, Greenwood-Nimmo M (2014) Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. Festschrift in honor of Peter Schmidt. Springer, New York, NY, pp 281–314
15. Solow RM (1956) A contribution to the theory of economic growth. Q J Econ 70(1):65–94
16. Ullah S, Ozturk I, Majeed MT, Ahmad W (2021) Do technological innovations have symmetric or asymmetric effects on environmental quality? Evidence from Pakistan. J Clean Prod 316:128239
17. Wang Y, Shen N (2016) Environmental regulation and environmental productivity: The case of China. Renew Sustain Energy Rev 62:758–766
18. Wang Y, Sun X, Guo X (2019) Environmental regulation and green productivity growth: Empirical evidence on the Porter Hypothesis from OECD industrial sectors. Energy Policy 132:611–619
19. Zhang D, Mohsin M, Rasheed AK, Chang Y, Taghizadeh-Hesary F (2021) Public spending and green economic growth in BRI region: mediating role of green finance. Energy Policy 153:112256
20. Zhang S, Wu Z, Wang Y, Hao Y (2021) Fostering green development with green finance: An empirical study on the environmental effect of green credit policy in China. J Environ Manage 296:113159
21. Zhao X, Mahendru M, Ma X, Rao A, Shang Y (2022) Impacts of environmental regulations on green economic growth in China: New guidelines regarding renewable energy and energy efficiency. Renewable Energy 187:728–742
22. Zhou G, Zhu J, Luo S (2022) The impact of fintech innovation on green growth in China: Mediating effect of green finance. Ecol Econ 193:107308