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Towards a Green Economy in China? Examining the Impact of the Internet of Things and Environmental Regulation on Green Growth

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Abstract: The idea of green growth stresses the necessity for economic expansion while resolving environmental issues, notably climate change. The Internet of Things (IoT) and environmental regulations have the potential to support green growth. Therefore, this study intends to examine the empirical link between the IoT, environmental regulations, and green growth in China by utilizing the autoregressive distributed lag (ARDL) and quantile autoregressive distributed lag (QARDL) methods to analyze data from 1997 to 2021. Data are obtained from reputable local and international sources like the Organisation for Economic Co-operation and Development (OECD), World Development Indicators (WDI), the Energy Information Administration (EIA), and the National Bureau of Statistics of China. Findings derived from the baseline ARDL model prove that the IoT, environmental regulations, renewable energy consumption, and research and development (R&D) encourage long-run green growth. Likewise, the robust model also highlights that the internet, environmental policy stringency, renewable energy consumption, and R&D help encourage green growth. In the short run, environmental policy stringency and the internet are favorably linked to green growth in the robust model, and renewable energy consumption is favorably linked to green growth in the baselines model; however, environmental regulation is negatively linked to green growth. The findings from the QARDL analysis show that the impact of the IoT on promoting green growth is significant across all quantiles. On the other hand, the effects of environmental regulation are more pronounced at higher levels of green growth. These findings imply that policymakers should try to increase the role of digitalization in society by promoting the IoT and the internet to decouple economic growth and environmental pollution. Moreover, the digitalization policy should be supported by implementing strict environmental laws and regulations.

Keywords: Internet of Things; environmental regulation; green growth; climate change

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1. Introduction

China has made incredible progress after the reforms and approval of the liberalization policy. But the intense quest for rapid economic expansion has produced a number of ecological and social issues. With China's economy strengthening, regional disparities, the widening wealth–poverty gap, and the degradation of the natural environment have gained prominence [1]. These issues have made it difficult for people to share the advantages of growth and have posed significant obstacles to green development, where adverse ecological effects and detrimental effects on social equity are frequently overlooked [2]. The idea of green growth, which attempts to integrate the objectives of developed nations with green growth and the comprehensive development of emerging nations, was first put out after the Rio +20 Summit in 2012. Green growth was made clearer in the 2015 United Nations Sustainable Development Goals agenda, which also offered suggestions for changing China's economic development paradigm [3]. Coordination of the three frameworks that govern the economy, society, and environment will effectively offer a road for sustainable growth as China enters a phase of excellent growth. This prompts a shift away from rapid economic growth towards the preservation of the environment, closing the wealth gap, and ensuring that the current social strata benefit equally from economic growth while also taking into account the wants of future generations [4]. The future of China's economy and significant changes in the global economic environment will be determined by this transition, which incorporates the integrated ideals of efficiency and equality.

The Chinese federal government first mentioned the idea of green growth in the 12th Five-Year Plan (FYP) initiated in 2011. Promoting the peaceful coexistence of humans and nature requires conserving and managing the ecological environment, which has grown to be a significant planning issue [5]. Dealing with challenges like China's conventional development mode's lack of "greening" is, thus, vital. Therefore, green growth is the goal for China's future. Thus, finding the factors that can influence green growth in China is crucial. In recent times, the digitalization of the economy and environmental regulations are considered vital in impacting sustainable and green growth [6]. Consequently, this study investigates the influence of the IoT and environmental guidelines on green growth in China.

Information and communication technology (ICT) is rapidly evolving and being used, which is changing many aspects of life and transforming it from an "industrialized" civilization to a global "knowledge" society [7]. The management of people's lives, interactions with others, and participation in many social areas are changing as a result of new ICT technologies, particularly the IoT. As a worldwide network, the IoT consists of four different types of tangible items [1]. Connecting people and things anytime, with anything and anybody, anyway, and anywhere, significantly transforms and affects the daily activities of individuals, businesses, and society. People, destinations, companies, and infrastructure are now linked in previously unheard-of ways thanks to the internet, mobile computing, and the IoT [8]. Despite the significant advantages of technology and the "smartness" that the IoT brings to numerous aspects of society, the rapid development of ICT encourages more waste, releases of greenhouse gases, and the usage of nonrenewable resources [9]. ICT products and systems have increased energy needs due to resource-intensive manufacturing and delivery, and rising amounts of diverse waste have the possibility of harming both human health and the environment [10]. As a result, it presents significant obstacles to both green development and green practices. On the other hand, by fostering energy efficiency, water conservation, waste management, sustainable transportation, and sustainable agriculture, the IoT provides an opportunity to transform green and sustainable growth [11]. The IoT can track and improve energy use, identify and stop water waste, better manage trash, encourage sustainable transportation, and improve agricultural methods via IoT-enabled sensors and gadgets. Real-time data and analytics have the capacity to help us build a more sustainable future and save the environment [12]. We can create a greener and more sustainable world with the aid of the IoT, which presents a number of opportunities for creativity and teamwork.

Environmental regulations are widely acknowledged as vital complementary policies for the success of any sustainable policy [13]. Governments often use various policy instruments to carry out environmental control policies to promote green development and safeguard the ecosystem [12]. Environmental control regulations always directly impact business-level output choices, such as redistributing resources, capital expenditure, and opportunities for innovation [14]. In particular, despite environmental regulations imposing an administrative cost on regulated businesses, the primary vehicle they offer is that regulation can encourage innovations intended to improve product quality and reduce manufacturing expenses, subsequently enhancing resource allocation proficiency and product worth [15]. According to Porter's hypotheses, businesses' productivity will increase when prompted, and innovation may reduce the costs associated with complying with regulations [16]. Thus, the strict environmental control policy is expected to have an impact on both environmental quality and economic performance.

In contrast, stricter environmental regulations entail a higher cost to businesses, requiring them to divert resources away from their more conventionally "productive" activities and towards pollution control [17]. Due to the comparatively high compliance expenditures brought on by environmental restrictions, the motivation for innovation is diminished. As a result, the short-term increase in enterprises' productivity may slow considerably [18]. In addition, by placing restrictions on industrial conduct, severe environmental regulation hurts industry-level efficiency and competitiveness. For instance, if environmental rules raise obstacles to entry, businesses' entry–exit processes will decelerate, fierce competition will be lessened, and industry productivity will decline. In order to circumvent legislation, large polluters may even be forced to migrate overseas by strict environmental regulations [19]. While advantageous to the environment, the closure of these businesses ultimately impacts local industry growth and production. Environmental regulations, therefore, can play the role of a double-edged sword that can foster green growth by encouraging investment in green innovation activities but can also hinder the firms' overall productivity by raising their costs. Hence, implementing environmental regulations to control the environmental effects of economic activities is a tricky task and must be handled with great caution.

Environmental regulations and the IoT have significant impacts on green growth and climate change mitigation. The IoT enables real-time data collection and automation, optimizing resource usage and increasing efficiency [20]. This fosters green growth, cost savings, and productivity gains. The IoT also drives innovation, creates new business opportunities, and stimulates investment in sectors like smart grids and renewable energy. Additionally, environmental regulations incentivize businesses to adopt cleaner technologies, invest in R&D, and manage climate-related risks. Together, these factors contribute to job creation, economic growth, and the expansion of the green economy [21,22]. Previous research on the subject of green growth in China has utilized the ARDL model and explored similar types of variables as those used in the present study. For instance, a study by Li et al. [23] employed the ARDL approach to analyze the relationship between ICT and green growth in China. Their findings indicated that ICT positively influenced economic growth in the long run and short run. Zheng et al. [24] also conducted research using the QARDL method and found similar results regarding the positive impact of ICT on green growth. Zhao et al. [25], using the QARDL method, found a substantial positive impact of environmental regulation on green growth.

Due to the significance of the IoT and environmental regulation as a determinant of green growth, the primary motive of the analysis is to investigate the influence of the IoT and environmental regulations on green growth in China. Research on the impact of the IoT and environmental regulation on green growth is a rapidly growing field. However, there are still some research gaps. There is a lack of a comprehensive understanding of the IoT and the effectiveness of environmental regulation in promoting green growth. There is a limited understanding of the relationship between the IoT and environmental regulation and how this relationship impacts green growth. There is a lack of a standardized methodology for measuring and analyzing the impacts of the IoT and environmental regulation on green growth. There are limited data on the environmental impact of the IoT, which makes it difficult to measure the overall impact of the IoT on green growth. Furthermore, a detailed and up-to-date analysis of China is still lacking. Addressing these gaps will help researchers gain a comprehensive understanding of the impact of the IoT and environmental regulation on green growth. As a result, this analysis adds the following to the existing body of literature. To our knowledge, this is the first study to examine how the IoT affects green development in China. Secondly, examining how China's stringent environmental restrictions affect green development is another contribution of this study. Third, this study is the first to analyze China's green growth model while taking into account the IoT and environmental regulations. Fourth, the study uses the ARDL and

QARDL to examine the aforementioned connection in China. Finally, the study's findings may provide important guidance for China's sustainable future.

2. Literature Review

The Internet of Things represents a groundbreaking conceptual shift in the IT sector. The expression "Internet of Things", often known as "IoT", is made up of the words "internet" and "Things". Connects billions worldwide through the internet network framework. Tens of thousands of private, government, educational, and commercial organizations, ranging in scope from local to worldwide, are connected via an array of electrical, movable, and optical network infrastructures [26].

The IoT significantly influences current enterprises, business structures, and operations. It is causing the current phase of the industrial revolution. This new technology development will be integrated across a variety of industries, including farming, city planning, energy management, and more, in addition to manufacturing [27]. A detonation of technical, economic, and global advantages will result from this progress. It will boost global GDP and provide individuals with new commercial, technological, and job options everywhere. The IoT is expected to raise average earnings and living conditions, just as previous revolutions did, mostly in industrially developed countries [28]. Since the IoT is a relatively new technical innovation, there hasn't been much academic study on its (possible) economic and environmental effects outside of certain management consulting literature [29]. However, a significant body of research exists on the economic and environmental effects of ICT.

The transition to a less capital-intensive economy where information resources substitute for physical ones, is made feasible by the growing influence of ICTs across all economic sectors [30]. In order to reduce greenhouse gas emissions, officials throughout the globe have confidence in ICT. Many studies now show that investing in ICT boosts productivity, fosters economic growth, and reduces energy intensity [31]. Nevertheless, several studies have shown that manufacturing ICT-related goods raises the industrial sector's need for energy, and their greater consumption also raises the home and service sectors' energy demands [32]. The increased utilization of ICT goods may have negative environmental effects owing to a boost in energy use, but it can also have positive economic effects [33].

There is a lack of empirical work on the impact of environmental policies on green development. As of yet, two large categories of thinking have emerged as crucial sources for this investigation. The first focuses on calculating a green growth index, whereas the second examines how the index responds to outside restrictions. Notwithstanding the lack of a widely accepted definition and estimating method, academics and policymakers have made an attempt to create scientific and comparable metrics to represent the green development of the economy at different levels. Two distinct categories of estimation techniques have been developed so far. One is calculated using the energy and carbon intensities as single-factor measures. These metrics have been applied by Bromley [32] and Wu et al. [33] to examine economic levels of greenness.

Total factor productivity (TFP) investigation has been used more frequently in conjunction with advancements in Data Envelopment Analysis (DEA) approaches and its production framework to take into account green growth by measuring the adverse impacts (i.e., ecological effects) of economic activities [34]. Such total factor techniques are more thorough and enlightening than single factor measures, particularly when looking at green development patterns from an ongoing angle. For instance, Shi and Li [35] discovered that the dynamic TFP of carbon footprints can be used as an indicator to indicate the green development impact of production companies in China using a "Directional Distance Function (DDF)—Malmquist model". Lin and Benjamin [36] investigated a non-radial DDF to build a "green development growth index (GDGI)" for Chinese provinces while taking energy efficiency and environmental pollutants into account.

The PH asserts that properly constructed rules encourage economic entities to seek green technologies, which will improve their competitiveness and output. In parallel with compliance expenses, and particularly over time, economic advantages will be produced. As a result, a "win-win" scenario is anticipated to develop as both the environment and the economy improve. Numerous studies, including those by Alexopoulos et al. [37], have experimentally examined and validated this claim. However, the competing theory of PH within the neoclassical belief is somewhat validated by further research, as illustrated by Greenstone et al. [38]. According to this perspective, the conflict between economic benefits and regulations cannot be resolved, since environmental laws would reduce the market advantages of firms by imposing additional costs. According to these two competing hypotheses, the deployment of abatement reduction arrangements is considered "neutral" if it has no impact on growth rates [39]. Furthermore, it should be noted that heterogeneous relevant goals and different regulatory design rationalities might result in contentious findings when seen from a broad viewpoint.

The direct link between environmental rules and sustainable and green growth hasn't, however, received much research attention. In one of the few investigations to look at such relationships, Shen et al. [22] observed the links between environmental demands, technology advancement, and green growth on a regional scale. The research looked at how market-based laws and executive orders affected environmentally friendly growth, and the results showed that regulations typically had a detrimental influence on local economic development. Nevertheless, this effect could be reversed if technique innovation serves as an arbitrator. Qiu et al. [40] looked at the direct and indirect effects of Chinese municipal and civic law on green TFP. The research results demonstrated that while "high- and low-political cities" benefited from civil constraints, local laws had different effects on them.

The following shortcomings in the literature are evident from the foregoing discussion. First, the influence of the IoT on green growth is not well supported by a great deal of empirical evidence. Second, the Porter hypothesis was used to evaluate the impact of environmental legislation on green growth, and inconsistent results were found. Third, the majority of empirical research has looked at how environmental rules affect business production at the micro level and overlooked the link between environmental policies and green growth at the macro level. Last but not least, the bulk of earlier studies looked at ecological behavior via CO_2 emissions; however, our study will analyze it via green growth. To further understand how the IoT and environmental laws affect green development, we thus need additional empirical evidence at the macro level.

3. Theoretical Framework, Methodology, and Data

Green growth theory emphasizes the importance of sustainability in economic growth [41]. It posits that environmental regulation and sustainability can be integrated into economic policies to promote long-term economic growth. Green growth theory suggests that technological advancements, such as the IoT, can be leveraged to achieve sustainable economic growth while reducing negative environmental impacts [9]. ICT enables people to acquire, access, save, and handle information. ICT plays a significant role in promoting the adoption of environmentally friendly practices within the IoT domain and offers various benefits to the general public [42]. These benefits include reducing energy consumption in the production and delivery of ICT facilities and devices. While the potential of ICT is intriguing, its application has been limited to a few specific situations and circumstances. In addition, ICT solutions for green infrastructures, such as smart transportation, smart buildings, and parking control, have a significant role in reducing CO_2 and the use of energy [43]. In this context, Tabaa et al. [44] introduced and addressed green computing abilities as well as green ICT and IoT, which depend on a green power grid and thus contribute to the overall green transformation of the economy. Real-time data collection, analysis, and transmission are incorporated into IoT-enabled smart systems to optimize resource utilization and enhance environmental performance. These systems enable intelligent decision-making and automatic actions depending on environmental circumstances, promoting more environmentally friendly practices in various industries [45]. Similarly, the internet provides access to a wealth of information and knowledge related to environmental sustainability [12]. The internet facilitates communication and collaboration among various stakeholders involved in green growth initiatives. The internet has revolutionized the way goods and services are bought and sold, providing opportunities for sustainable consumption. Online marketplaces enable the exchange of used goods, promoting reuse and reducing the demand for new products. E-commerce platforms also facilitate access to environmentally friendly products, such as energy-efficient appliances and eco-friendly alternatives. The internet enables consumers to make informed choices, compare prices, and contribute to the demand for sustainable products and services. Emerging literature has reported that the IoT has a positive impact on green growth by increasing resource efficiency, environmental monitoring, smart buildings, and smart transportation [12].

Environmental regulation has direct and indirect impacts on economic growth. Direct impacts include the cost of compliance with environmental regulations, while indirect impacts include the potential benefits of reducing negative environmental impacts on health and other economic activities [13,45]. Environmental regulations create market demand for environmentally friendly technologies, products, and services. By setting standards and targets for emissions reduction, energy efficiency, waste management, and other environmental parameters, regulations incentivize businesses to invest in research, development, and innovation to meet these requirements. This stimulates the growth of green industries, such as renewable energy, clean technology, sustainable agriculture, and waste management, creating new job opportunities and economic growth. Environmental regulations drive innovation by pushing businesses to develop and adopt cleaner and more sustainable technologies and practices. Environmental regulations provide a stable and predictable regulatory environment that boosts investor confidence in green sectors. According to Porter's theory [46], well-designed and effectively implemented environmental regulations stimulate green innovation, competitiveness, and, thus, green growth. This theory contends that firms are motivated to develop and use cleaner technology and processes when faced with tighter environmental regulations. This innovative approach to laws may lead to financial savings, higher output, and the creation of new business prospects, eventually fostering green growth. The study assessed the relationship between the IoT, environmental regulation, and green growth by evaluating the following hypotheses:

H1. *There is a significant positive association between the IoT and green growth.*

H2. *Increased environmental regulation has a positive effect on green growth.*

This study, building upon previous literature, examines the influence of environmental regulation and the IoT on the promotion of green growth. Thus, based on the theoretical framework, the model can be written as follows:

$$\mathrm{GG_t} = \varphi_0 + \varphi_1\mathrm{IoT_t} + \varphi_2\mathrm{ER_t} + \varphi_3\mathrm{RD_t} + \varphi_4\mathrm{REC_t} + \varepsilon_t \quad (1)$$

Specification (1) is the green growth (GG) function that relies on the Internet of Things (IoT), environmental regulation (ER), research and development (RD), and renewable energy consumption (REC). The coefficients φ_1, φ_2, φ_3, and φ_4 represent their effects on green growth, while φ_0 is the constant term and ε_t represents the error term. Estimates of the long-run coefficients associated with the variables from Equation (1) are available. This study focuses on both short and long-run estimates. Therefore, it is essential to incorporate the short-term dynamics in Equation (1). To achieve this, Equation (1) is designated as an error correction structure. Following previous research, the bounds-testing method for cointegration and error-correction modeling proposed by Pesaran et al. [47] is employed as indicated by Equation (2):

$$
\begin{aligned}
\Delta \mathrm{GG_t} = \varphi_0 + \sum_{k=1}^{n} \beta_{1k}\Delta \mathrm{GG_{t-k}} + \sum_{k=0}^{n} \beta_{2k}\Delta \mathrm{IoT_{t-k}} + \sum_{k=0}^{n} \beta_{3k}\Delta \mathrm{ER_{t-k}} + \sum_{k=0}^{n} \beta_{4k}\Delta \mathrm{RD_{t-k}} + \sum_{k=0}^{n} \beta_{5k}\Delta \mathrm{REC_{t-k}} \\
+\varphi_1 \mathrm{GG_{t-1}} + \varphi_2 \mathrm{IoT_{t-1}} + \varphi_3 \mathrm{ER_{t-1}} + \varphi_4 \mathrm{RD_{t-1}} + \varphi_5 \mathrm{REC_{t-1}} + \varepsilon_t
\end{aligned}
\quad (2)
$$

Specification (2) is formally known as the ARDL model. In Equation (2), the symbol "Δ" signifies a change, φ_0 represents the constant term, and ε_t represents the error term. The coefficients β_{1k}, β_{2k}, β_{3k}, β_{4k}, and β_{5k} correspond to the long-run coefficients, while φ_1, φ_2, φ_3, φ_4, and φ_5 represent the short-run coefficients. The subscript "k" in Equation (2) indicates the lag order of the variables. Coefficient estimates associated with Δ variables represent short-run impacts, whereas estimates of φ_2 and φ_6 divided by $-\varphi_1$ indicate long-run impacts under the aforementioned specification (2). One of the biggest contributions of this method to econometric literature is its strong ability to provide short and long-run estimates. Pesaran et al. [48] suggest a test for cointegration that should be used if these long-run estimates are to have any useful value. To determine the significance of the estimates, we use the ECM, which needs to be negative, as suggested by Pesaran et al. [48]. It is apparent that the dispersion of these tests is nonstandard. Consequently, new critical values are developed, considering the integrating characteristics of the variables. In fact, using this method, variables may be a combination of I(0) and I(1). The pre-unit-root analysis is unnecessary because many macro variables have these characteristics. Another important benefit of this method is its power to perform well in cases where data length is small across time. Finally, the issues of endogeneity and heterogeneity can be addressed by applying this method because it includes a short-run adjustment mechanism in the model.

A few other diagnoses are also presented to check whether our estimates are valid or not. First, the Lagrange Multiplier (LM) measure is used to prove whether the residuals are autocorrelation free or not. Ramsey's RESET test is applied to see whether there is any specification bias in the model. Both these tests have Chi-square (χ^2) distribution with one degree of freedom. CUSUM and CUSUM-sq checks are performed on the residuals of the framework to assess the robustness of both short-run and long-run estimations. These checks are utilized to evaluate the stability and reliability of the results obtained from the analysis. Although the baseline model is ARDL, the study has used the QARDL model to check the robustness of our results. The QARDL model provides correct estimates when non-normality occurs. The QARDL method offers several notable advantages in econometric analysis [49]. Firstly, it is adept at capturing nonlinear relationships between the variables of interest. Unlike traditional linear models, QARDL provides more efficient estimates, enhancing the accuracy and reliability of the results. Additionally, QARDL effectively addresses endogeneity concerns by incorporating lagged dependent variables as instrumental variables, leading to more robust estimates in the presence of endogenous variables. Furthermore, QARDL allows for the estimation of both short- and long-run coefficients, providing valuable insights into the dynamics of the relationships under investigation. Moreover, the method enables estimation at multiple quantiles, enabling a comprehensive examination of the effects across different segments of the distribution. Overall, QARDL has proven to be a powerful and versatile tool for analyzing complex relationships in empirical research. The methodology framework of the study is reported in Figure 1.

The study examines the impact of the IoT and environmental regulation on green growth in China. For this, the study has collected time series data for the period 1997 to 2021, and the details about the data are given in Table 1. Green growth (GG) was assessed through pollution-adjusted GDP growth as a percentage. GG data series were collected from the OECD. The market size of the Internet of Things (IoT) in billion Yuan was used to measure Internet of Things (IoT) variables. The data series for the IoT was collected from the National Bureau of Statistics of China. Another focused variable was environmental regulation (ER), which was measured by environment-related taxes as a % of GDP, and the data source for ER was the OECD. To confirm the robustness of the findings, the study used other proxy measures of Internet of Things and environmental regulation. These are the internet users (Internet) and environmental policy stringency (EPS). Individuals using the internet, as a % of the total population, were taken as a measure of internet users. The required data series was collected from the WDI. Meanwhile, EPS was measured through an index, which was calculated by OECD. Research and development (RD) and renewable energy consumption (REC) are control variables in our model. The literature provides evidence for the positive nexus between REC and GG [50]. In another study, Li et al. [1] reported the positive impact of research and development on green growth. Following Chen et al. [6], the RD variable was measured through research and development expenditures as a % of GDP, and the data series was sourced from the WDI. Data on the total consumption of energy from all sources (renewables, nuclear, and others) was taken to measure REC, and the source of the data series was EIA (see Table 1). Table 2 displays the outcomes of important statistical tests. The mean of the variables is positive. These are reported as: 9.089 for GG, 4.904 for IOT, 2.495 for Internet, 0.926 for ER, 1.518 for EPS, 1.576 for RD, and 9.387 for REC. The S.D scores are reported as: 1.298 for GG, 1.944 for IOT, 1.978 for Internet, 0.422 for ER, 1.184 for EPS, 0.559 for RD, and 7.223 for REC. The J.B statistics show that only the ER series follows a normal distribution in our model.

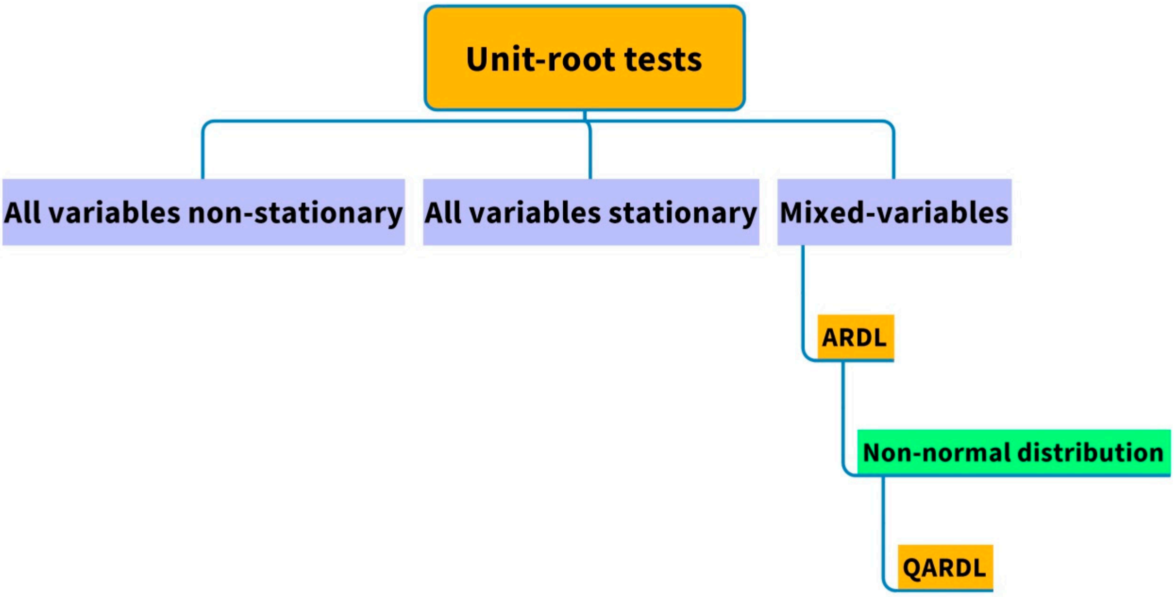

Figure 1. Methodology framework.

Table 1. Definitions and sources.

Variables	Symbol	Definitions	Expected Outcomes	Sources
Green growth	GG	Pollution-adjusted GDP growth (%)		OECD
Internet of Things	IoT	Market size of Internet-of-Things (IoT) (billion yuan)	+/−	National Bureau of Statistics of China
Internet users	Internet	Individuals using the internet (% of population)	+/−	WDI
Environmental regulation	ER	Environmentally related taxes, % GDP	+/−	OECD
Environmental policy stringency	EPS	Environmental Policy Stringency Index	+/−	OECD
Research and development	RD	Research and development expenditure (% of GDP)	+/−	WDI
Renewable energy consumption	REC	Total energy consumption from nuclear, renewables, and other, China, Annual	+/−	EIA

Table 2. Descriptive statistics.

	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	Prob.
GG	9.089	9.211	13.491	6.923	1.298	1.252	5.391	49.92	0.000
IOT	4.904	5.136	7.441	1.184	1.944	−0.373	1.839	7.926	0.019
Internet	2.495	3.366	4.297	−4.095	1.978	−1.518	4.776	51.53	0.000
ER	0.926	0.942	1.763	0.095	0.422	−0.059	2.918	0.086	0.958
EPS	1.518	0.964	3.944	0.206	1.184	0.330	1.472	11.53	0.003
RD	1.576	1.670	2.517	0.627	0.559	−0.150	1.800	6.371	0.041
REC	9.387	7.017	25.555	1.773	7.223	0.717	2.204	11.20	0.004

4. Empirical Results

Since using non-stationary variables may lead to inaccurate results, the first step in a time series inquiry is determining whether the selected variables are stationary. In econometrics, some of the most famous unit root tests are "Augmented Dickey–Fuller (ADF) and DF-GLS". However, these unit root tests are inefficient in detecting structural breaks within a given series, and, thus, may provide misleading results. Consequently, the unit root tests with and without structural breaks have been applied in this analysis. Tables 3 and 4 highlight the results of the unit root tests. From Table 3, it can be observed that, except for Internet and ER, all other variables exhibit stationarity at I(1) according to the ADF test. In the case of the DF-GLS, all variables except ER are stationary at I(1). Similarly, the unit root test results with structural breaks infer that GG, ER, EPS, RD, and REC are stationary at I(1), whereas IoT and Internet are stationary at I(0). Hence, it is concluded that the variables included in the analysis are I(0) or I(1).

Table 3. Unit root test with non-structural break.

	ADP			DF-GLS		
	I(0)	I(1)	Decision	I(0)	I(1)	Decision
GG	−2.276	−2.794 *	I(1)	−0.801	−2.319 **	I(1)
IOT	−1.924	−2.636 *	I(1)	−0.192	−1.641 *	I(1)
Internet	−2.939 **		I(0)	1.395	−1.799 *	I(1)
ER	−2.613 *		I(0)	−1.988 **		I(0)
EPS	0.447	−3.019 **	I(1)	0.861	−1.712 *	I(1)
RD	−1.023	−3.021 **	I(1)	0.632	−1.658 *	I(1)
REC	0.447	−2.919 **	I(1)	0.861	−1.802 *	I(1)

Note: ** $p < 0.05$, * $p < 0.1$.

Table 4. Unit root test with structural break.

	I(0)	Break Date	I(1)	Break Date	Decision
GG	−2.921	2010 Q1	−5.245 ***	2000 Q2	I(1)
IOT	−5.685 ***	2005 Q2			I(0)
Internet	−10.02 ***	1997 Q4			I(0)
ER	−2.871	2007 Q2	−5.012 **	2000 Q1	I(1)
EPS	−1.898	2011 Q1	−4.921 **	2000 Q3	I(1)
RD	−2.542	2008 Q1	−5.365 ***	2000 Q4	I(1)
REC	−1.985	2011 Q2	−4.958 **	2000 Q3	I(1)

Note: *** $p < 0.01$, ** $p < 0.05$.

After applying the unit root tests, the study has concluded that our variables are either I(0), i.e., stationary at level, or I(1), i.e., stationary at first difference. This means that variables included in the analysis are based on a mixed order of integrations, i.e., I(0) and I(1). The variables' mixed order of integrations induces us to apply the ARDL model that can deal with these types of variables. Most of the macroeconomic variables are either I(0) or I(1); therefore, a large number of studies that have applied the time series analysis used the variables with mixed orders of integration [25]. Particularly, there are studies which used ICT [7] and environmental regulations [26] in a time series analysis using the ARDL approach due to its ability to handle the variables of mixed order of integrations.

After considering the unit root results, the ARDL framework was employed to handle a combination of variables that were either stationary at level (I(0)) or stationary at first difference (I(1)). As presented in Table 5, this methodology enabled the simultaneous estimation of both short-run and long-run outcomes. Two distinct models were computed, including a baseline model and a robustness test, to examine the reliability of the findings. The long-run estimates of IoT and Internet are positively significant in the baseline and robust models—a 1% increase in IoT and Internet causes the green growth to rise by 1.588% and 1.483% in the baseline and robust models, respectively. Consequently, our empirical results validated hypothesis (1). A 1% escalation of ER and EPS helps improve the green growth by 2.111% (baseline) and 1.604% (robust). Our empirical findings aligned with hypothesis (2). In addition to the main variables, the analysis also controls the effects of RD and REC, which help promote green growth by 0.580% (baseline) and 0.638% (robust) with every 1% increase in the RD and by 1.132% and 1.210% with every 1% increase in REC.

Table 5. ARDL estimates.

	Basic Model				Robustness			
Variable	**Coefficient**	**S-E**	**t-Stat**	**Prob. ***	**Coefficient**	**S-E**	**t-Stat**	**Prob. ***
Short-run								
IOT	0.674	0.655	1.029	0.306				
IOT(-1)	0.909	0.667	1.363	0.176				
Internet					2.397 *	1.372	1.747	0.084
Internet(-1)					1.470	1.202	1.222	0.225
ER	0.998	0.612	1.631	0.107				
ER(-1)	−1.138 *	0.616	−1.846	0.068				
EPS					1.286 ***	0.474	2.715	0.008
EPS(-1)					1.065 **	0.444	2.399	0.019
RD	0.148	0.153	0.967	0.336	0.110	0.161	0.684	0.496
RD(-1)	0.498	3.599	0.139	0.890				
REC	1.006 ***	0.279	3.603	0.001	−0.617	0.671	−0.919	0.360
REC(-1)	0.987 ***	0.281	3.519	0.001				
Long-run								
IOT	1.588 **	0.732	2.170	0.033				
Internet					1.483 ***	0.080	18.47	0.000
ER	2.111 ***	0.777	2.718	0.008				
EPS					1.604 ***	0.604	2.655	0.010
RD	0.580 ***	0.210	2.764	0.007	0.638 ***	0.082	7.789	0.000
REC	1.132 ***	0.345	3.284	0.002	1.210 ***	0.340	3.555	0.001
C	7.405 ***	1.936	3.825	0.000	3.911	4.064	0.962	0.339
Diagnostics								
F-test	4.589 **				5.685 ***			
ECM	−0.348 **	0.168	−2.076	0.041	−0.544 **	0.266	−2.041	0.045
LM	1.033				0.548			
RESET	0.698				1.588			
CUSUM	S				S			
CUSUM-sq	S				S			

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

In the short run, most of the estimates are insignificant except for Internet and EPS, which are positively linked to green growth in the robust model, while the REC is positively linked to green growth in the baseline model. A 1% rise in Internet and EPS improves green growth by 2.397% and 1.286%, respectively. Likewise, a 1% improvement in REC causes the green growth to improve by 1.006%. However, the estimated coefficient of ER (1.138%) is negatively linked to green growth in the baseline model.

The precision of our estimates has been verified by several diagnostic tests, including LM, RESET, CUSUM, and CUSUM-sq. For instance, LM and RESET tests have shown that our model is serial correlation and misspecification free. The CUSUM and CUSUM-SQ tests further support the stability of our model. The F-test and ECM tests are used to determine if variables are co-integrated, and both results demonstrate the validity of the variables' long-term connection.

The QARDL frameworks are used to test the robustness of our findings, which is a suitable model if the data dispersion is not uniform. Table 6 provides the results of the QARDL framework. The estimates of IoT promote green growth in the long run at all of its magnitudes, i.e., from the 5th to the 95th quantiles, whereas ER, RD, and REC promote green growth only at higher magnitudes of green growth. Specifically, the estimates of ER are positive and significant from the 70th to the 95th quantiles; the estimates of RD and REC are positively connected to green growth from the 80th to the 95th quantiles. In the short run, only RD is positively connected to green growth from the 50th to 95th quantiles, and ER is positively connected in the last two quantiles.

Table 6. QARDL estimates (robustness).

	Long-Run				**Short-Run**							
	IOT	**ER**	**RD**	**REC**	**IOT**	**ER**	**ER(-1)**	**RD**	**REC**	**REC(-1)**	**C**	**ECM**
0.05	2.290 ***	0.620	0.967	0.117	0.528	2.240	−1.198	0.624	1.314	1.220	8.483 ***	−0.834 ***
	2.753	0.976	1.389	1.584	0.893	1.628	−1.208	0.360	0.987	0.460	10.71	−16.29
0.10	1.839 *	0.548	0.861	0.128	0.523	2.073	−0.838	1.051	1.304	1.209	8.635 ***	−0.807 ***
	1.817	0.796	1.011	1.506	1.147	1.572	−1.481	0.450	1.003	0.865	9.219	−12.85
0.20	0.317 *	0.356	0.538	0.113	0.355	1.483	−0.719	0.999	1.227	1.135	7.968 ***	−0.751 ***
	1.703	0.357	0.809	0.837	1.123	1.533	−1.555	0.462	1.098	0.921	8.500	−7.534
0.30	0.494 **	0.481	0.374	−0.011	0.290	1.390	−0.620	1.888	1.043	0.954	7.426 ***	−0.718 ***
	3.091	0.948	0.439	−0.222	1.255	1.180	−1.647	0.790	1.181	1.088	17.87	−6.448
0.40	0.429 ***	0.436	0.184	−0.015	0.249	1.124	−0.592	1.300	0.966	0.886	7.521 ***	−0.644 ***
	2.591	0.843	0.204	−0.291	1.434	1.111	−1.321	0.403	1.242	1.144	16.01	−4.844
0.50	0.477 **	0.296	0.425	−0.018	0.168	0.273	−0.451	1.496 ***	0.491	0.416	7.633 ***	−0.622 ***
	2.510	0.528	0.432	−0.306	1.643	0.663	−1.202	3.185	1.506	1.567	14.80	−6.289
0.60	0.465 **	0.256	0.473	−0.012	0.112	0.260	−0.602	1.718 ***	0.494	0.425	7.694 ***	−0.616 ***
	2.550	1.065	0.494	−0.210	1.475	0.817	−1.373	2.748	1.603	1.473	15.08	−5.944
0.70	1.081 ***	0.610 *	0.779	0.071	0.083	0.169	−0.750	1.977 ***	0.267	0.192	9.188 ***	−0.612 ***
	2.641	1.812	1.615	1.255	1.308	0.641	−1.459	3.132	1.127	0.822	7.539	−8.935
0.80	1.868 *	0.700 **	0.998 *	0.083 **	0.058	0.195	−0.872	2.018 ***	0.226	0.139	10.05 ***	−0.619 ***
	1.773	2.034	1.700	2.117	0.944	0.755	−1.517	2.724	1.121	0.702	3.358	−11.29
0.90	2.361 ***	0.915 **	1.015 *	0.013 **	0.068	0.400 **	−1.137	1.772 **	0.232	0.133	11.52 ***	−0.609 ***
	2.835	2.388	1.878	2.422	1.151	2.103	−1.593	2.156	1.308	0.770	1.835	−12.98
0.95	2.780 ***	1.163 ***	1.226 **	0.354 ***	0.361	0.539 **	−1.209	1.475 ***	0.205	0.129	12.31 ***	−0.745 ***
	4.666	3.162	2.374	3.021	1.559	2.364	−1.614	3.293	1.004	0.635	3.942	−7.835

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

5. Discussion

In baseline and robust models, the long-term estimates indicate a positive and significant impact of the IoT and the internet on green growth. The positive nexus between the IoT and the green economy is supported by various previous studies. For instance, Almalki et al. [9] reported that IoT devices help monitor and manage energy consumption in buildings, factories, and homes. The study argues that by providing real-time data on energy usage and enabling automatic adjustments to reduce waste, the IoT can contribute to energy efficiency, which in turn can promote green growth. Ding et al. [12] described that IoT-enabled waste management systems help reduce landfill waste and improve recycling rates by monitoring and optimizing waste collection and disposal. This leads to a more sustainable approach to waste management, which ultimately contributes to green growth. Mnyakin [47] reveals that IoT devices optimize traffic flow, reduce fuel consumption, and promote the use of public transportation, bicycles, and other sustainable modes of transportation. By promoting sustainable transportation options, the IoT contributes to reducing emissions, which can support green growth. Moreover, IoT sensors track products and materials throughout the supply chain, providing visibility into the environmental impact and enabling more sustainable sourcing and logistics. This leads to more sustainable production and distribution practices, which contributes to green growth [51]. In short, our results infer that the IoT has a positive impact on green growth by improving the efficiency of resource utilization, reducing waste, and promoting sustainable practices. IoT devices can be used to monitor and optimize energy consumption, reduce emissions, and improve the efficiency of transportation and logistics.

Similarly, the long-run estimated coefficients of ER and EPS are positive and significant in baseline and robust green growth models. Fan et al. [52] supported our findings by arguing that environmental regulations can incentivize businesses to invest in new technologies that promote sustainability, such as renewable energy and energy-efficient appliances. This leads to technological innovation and adoption, which contributes to green growth. Another study reports that environmental regulations encourage businesses to adopt more efficient production processes that reduce waste and conserve resources such as water and energy. This leads to increased resource efficiency that enhances green growth [53]. Sun et al. [21] performed a study that also reports a positive nexus between environmental regulations and green growth. The study reveals that environmental regulations require businesses to use cleaner energy sources and reduce greenhouse gas emissions, which leads to a transition towards more sustainable energy production and use. This contributes to green growth by reducing environmental impact and promoting the use of renewable energy sources. Environmental regulations encourage the use of sustainable transportation options, such as public transportation, bicycles, and electric vehicles, by providing incentives and implementing policies such as emissions standards. This leads to a reduction in emissions and a more sustainable approach to transportation, which contributes to green growth [14]. Hsu et al. [54] reported that environmental regulations require businesses to adopt sustainable procurement practices, such as sourcing materials from sustainable suppliers, to reduce environmental impact and promote sustainable development. This contributes to green growth by promoting sustainable production and consumption practices. Our results also suggest that environmental regulation is an important driver of green growth by promoting sustainable practices, encouraging innovation, and creating new economic opportunities.

6. Conclusions

China's rapid economic growth over the past few decades has propelled it to become the world's second-largest economy, but it has come at a cost to the environment. As China continues to industrialize and urbanize, environmental issues such as air pollution, water pollution, and soil contamination have become major concerns, threatening public health and ecological sustainability. In response to these challenges, the Chinese government has introduced a range of environmental regulations and initiatives aimed at reducing pollution and promoting sustainable development. At the same time, the IoT has emerged as a transformative force in the global economy, offering new opportunities for businesses to improve efficiency, reduce waste, and increase productivity. IoT technologies have the potential to support environmental regulation and promote sustainable development by providing real-time data on resource use, enabling remote monitoring and control of industrial processes, and facilitating the optimization of energy consumption and waste management. This intersection of the IoT and environmental regulation is particularly relevant to China's green growth ambitions, which aim to balance economic growth with environmental protection and social development. As China continues to pursue its green growth agenda, IoT technologies have the potential to play a critical role in supporting the country's environmental objectives and promoting sustainable economic growth. There is a research gap concerning the combined effects of the IoT and environmental regulation on green growth, despite limited existing literature on the topic. In this context, this paper aimed to explore the impact of the IoT and environmental regulation on green growth in China, with a focus on how IoT technologies can be leveraged to support environmental protection and sustainable development. The paper aimed to contribute to the ongoing discussion about the role of the IoT and environmental regulations in promoting green growth in China. The main results of the study are as follows: (i) In the baseline model, the IoT, environmental regulation, R&D, and renewable energy consumption improve long-term green growth; (ii) In the robust model, the internet, environmental policy stringency, R&D, and renewable energy consumption expand green growth; (iii) In the short run, environmental policy stringency and the internet are favorably linked to green growth in the robust model and the renewable energy consumption is favorably linked to green growth in the baseline model; however, environmental regulation is negatively linked to green growth. The evaluated results not only fill critical gaps but also align closely with the findings of previous research.

6.1. Policy Implications

Based on the analysis, a number of policy suggestions are put forward to foster green growth in China. Firstly, the Chinese government should incentivize the development and adoption of IoT technologies in the industrial, transportation, and energy sectors. This could be done through tax breaks, subsidies, and other financial incentives, as well as through targeted investments in research and development. Secondly, the government should continue to strengthen environmental regulations and enforcement mechanisms to ensure that IoT technologies are used to support sustainable development and environmental protection. This could include mandatory reporting requirements for industrial and transportation emissions, as well as stricter penalties for non-compliance with environmental regulations. Third, the Chinese government should foster closer collaboration between industry and government to ensure that IoT technologies are being used effectively to support environmental protection and sustainable development. This could be done through public–private partnerships, joint research and development initiatives, and other forms of collaboration. Fourth, the government should prioritize investments in sustainable infrastructure, such as renewable energy, green transportation, and smart cities, which can leverage IoT technologies to optimize energy use and reduce environmental impact. Finally, the government should prioritize public education and engagement on the importance of sustainable development and environmental protection, as well as the potential benefits of IoT technologies in achieving these goals. This could be done through public awareness campaigns, education programs, and other outreach initiatives.

6.2. Limitations and Directions

Our study contains several limitations. The study only focuses on China and the results may not be applicable to other countries or regions. It is difficult to fully understand the impact of the IoT and environmental regulations on green growth in different regions of China. Further research is necessary to investigate the specific effects of these policies on the provinces and to better inform decision-making at the local level. The study only examines the short- and long-term effects of the IoT and environmental regulations on green growth, without considering potential nonlinear relationship effects. Future studies should examine the nonlinear and dynamic effects of the IoT and environmental regulations on green growth. Further research is needed to investigate the other potential determinants of green growth. Further research is needed to explore how China can collaborate with other countries to share best practices and promote sustainable development globally.

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