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How Does the Development of the Internet Affect Green Total Factor Productivity? Evidence From China

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ABSTRACT Green total factor productivity is not merely an inevitable choice to continuously increase the quality of China's economy, but also a booming demand to promote global development. With the fast development of the new generation information technology represented by world comprehensive web technology, Internet growth may well play a more crucial role in enhancing green total factor productivity in China. Based on 2009-2017 China's inter-provincial panel data, this article uses the threshold regression model and fixed-effect model to empirically investigate the influence intensity and internal mechanism of green total factor productivity in areas affected by the Internet development. We ultimately come to the following conclusions. First, there is a digital divide between the regions of China. Second, many factors such as Internet development, human capital, urbanization, energy efficiency, and external dependence all exert a positive influence on China's green total factor productivity. At the same time, government intervention is not conducive to green total factor productivity. Third, the influence of Internet growth on China's green total factor productivity is non-linear, based on the significant double threshold effect of human capital. As the level of human capital continues to exceed the threshold value, the effect of Internet expansion on the green total factor productivity of China has undergone a structural change. The result has changed from a weak negative influence to a positive one, and the significance is increasing. To advance the smart, green, and coordinated development among regions, it is necessary to bring "Internet +" into full play in promoting China's green total factor productivity, strengthen the deep integration of Internet development and industrial development, and improve the level of clean production utilizing network information.

INDEX TERMS Internet development, green total factor productivity, fixed-effect model, threshold effect, China.

I. INTRODUCTION

At present, global warming and constraints on resources are becoming more severe, and the contradiction among China's economic development, environmental protection, and resource consumption have become increasingly prominent. Improving Green total factor productivity(GTFP) is the crucial link of resolving the above contradictions and promoting the GTFP of the economy [1]. Nowadays, the Internet is the most active field of technology innovation. NGIT (a new

generation of information technology) represented with Internet technology as the core has been known as the sign of the fifth Kondratieff Cycle of the world economy [2]. The new media represented by the Internet and its technological paradigm have brought not only a convenient way of life but also produced some adverse effects. Cybersecurity issues will become a common challenge faced by humanity, such as Internet financial risks, personal information leakage, network infringement, network uncivilized behavior. However, the development of the global Internet is unstoppable, with the Internet being fully integrated into all fields of economic and social production and life, which will lead to new changes

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in social production [3]. Hence, only by deepening Internet application and strengthening Internet governance can the Internet better serve human development [4]. The outbreak of the COVID-19 epidemic also shows how Internet technology permeates every aspect of the economy, society, and life, such as online office, online education, e-commerce, etc. It can be said that compared with the SARS outbreak in 2003, the COVID-19 epidemic prevention and control is a complete response and assistance in the Internet era. To confirm the development trend, more and more countries have hoped to promote economic growth and enhance comprehensive national strength by constructing high-speed and universal Internet.

With the implementation of the “Broadband China” and “Internet +” strategies, the number of Internet users in China has gradually risen from 298 million to 854 million during the past 12 years. The Internet penetration rate even exceeded 50 percent, reaching 57.7 percent. The word “Internet” was mentioned eight times in the Nineteenth National Congress of the Communist Party of China. Also, President Xi Jinping emphasized the need to reinforce the construction of information infrastructure networks and cyber power and promoted the high convergence of information networks, AI, cloud computing, big data analysis, and the real economy. At present, to spur Internet development is no longer simply to emphasize its contribution to the total output value, that is, the information industry represented by the Internet in the GDP, but instead to systematically encourage the integrated innovation of “Internet + industry” to reshape the industrial organization form and industrial competition pattern, thus speeding up the green total factor productivity.

The reality of the deep integration of Internet technology and economic development needs theoretical interpretation, and the government’s policies to promote Internet development also require corresponding academic support [5]. According to the preliminary analysis, the academic community believes that the effect of Internet technology on green economic growth can be summarized in the following three aspects:

First, Internet technology promotes industrial transformation and upgrading by integrating resources, thereby boosting the GTFP cloud computing and intelligent manufacturing. The increasingly mature data economy model provides technical support for the upgrading and digital transformation of conventional enterprises to high-end intelligent manufacturing. Simultaneously, through Internet technology, information resources in all aspects of production and consumption can be integrated. The entire process from production to consumption can be connected to form industrial linkages and precise customer marketing, which inject new impetus into the GTFP.

Second, Internet technology promotes GTFP by building an ecological and environmental regulatory system. The concrete expression manifests in several respects. On the one hand, through the application and comprehensive development of Internet technology, the environmental protection

system and the enterprise’s ecological environment information can be integrated to form an overall and intact ecological environment data information system, which is conducive to both scientific decision-making and the careful supervision on the ecological environment. On the other hand, the Internet platform can be applied for real-time monitoring and accurate prediction of the ecological environment, thereby providing a basis for environmental environment protection and good governance and effectively promoting green development.

Third, Internet technology promotes GTFP through the establishment of public service platforms and databases. Specifically, with the accelerated expansion of the network and the formation of modern concepts such as green living, the sharing economy, mediated by the Internet, is gradually emerging and developing. Individuals provide idle resources to users in need of public service platforms through Internet technology to achieve social resource sharing, such as Airbnb and Uber. Through the matching of the civil service platform, the information island problem is effectively solved, and the fragmented suppliers and consumers are optimized in the platform simultaneously, which will be beneficial to green development in both production and living.

Internet technology is constantly innovating and developing, affecting green economic growth through the above three levels. So, after nearly a decade of development, what is the status of Internet development all over China? How much has the Internet contributed to the GTFP? What is the underlying mechanism for this action? Is this effect regionally heterogeneous? For the technological innovation and sustainable development of China and other developing countries, it is of high practical significance and educational value to accurately evaluate the role of the Internet in GTFP and to judge whether the Internet can form a new driving impetus for the high-quality development of Chinese economy in the modern era based on regional heterogeneity.

The possible marginal contributions of this paper are as follows: First, we have built a comprehensive regional Internet development level evaluation system in terms of Internet penetration rate, Internet infrastructure construction, Internet development environment. On this basis, we use accelerated genetic algorithms based on real numbers to improve the projection pursuit model, and then scientifically evaluate the Internet development index of 30 regions in China from 2009 to 2017. At the same time, make necessary analysis of its regional differences and trends. Second, based on the SBM directional distance function, we measured the green total factor productivity of various regions in China under the constraint of undesired output. Third, we empirically analyzed the driving factors of China’s green total factor productivity improvement, including variables such as Internet development and human capital accumulation. Fourth, in combination with the heterogeneity of regional human capital accumulation, we deeply explored the complex threshold characteristics between Internet development and green total factor productivity.

II. LITERATURE REVIEW

This article will sort out the literature related to this research through the following two aspects:

On the one hand, ever since Solow put forward the “Information Technology Productivity Paradox,” the research and debate on this paradox have been going on for a long time [6], [7]. In the past few years, with the widespread application and rapid development of a new generation of network information technology, it has attracted many scholars to conduct a lot of research on the economic effects of the Internet and information communication technology. Relevant researches mainly focus on the promoting effect and transmission mechanism of the Internet on the whole economic system, including economic growth, energy efficiency improvement, carbon dioxide emissions, etc.

On the other hand, the importance of GTFP for the high-quality development of the economy has been recognized by scholars. We will sort out the literature related to this article from four aspects: the concept and accounting of GTFP and the Internet’s influence on GTFP. The impact of human capital on GTFP, the driving factors of GTFP.

A. RESEARCH ON THE INFLUENCE OF INTERNET DEVELOPMENT ON ECONOMIC GROWTH

In earlier years, governments of all countries incorporated relevant data of Internet construction into their statistics on telecommunications infrastructure. Therefore, scholars have carried out many related studies on the relationship between economic growth and telecommunication infrastructure construction investment, which provided many referential methods for the study on the relationship between the Internet and economic expansion. Madden and Savage [8] believed that telecommunications infrastructure played an essential part in the economic growth of countries in transition. Similarly, Lin [9] argued that information and communication infrastructure had promoted the development of electronic commerce, which was necessary for both urban economic growth and industrial transformation. Moreover, taking China as an example, Zhang and Sun [10] also confirmed the existence of this promotion. Röller and Waverman [11] used OECD national panel data to further inquire into network effects. They found that when the fixed-line penetration exceeds the threshold value, its influence on economic development was more significant. Through the treatment and analysis of a large number of test data from G-20 countries, Pradhan *et al.* [12] held that the construction of Internet infrastructure improved informatization. Simultaneously, the comprehensive application of information technology speeded up economic development to a greater extent.

Based on the analysis of Internet development and economic growth, some other scholars put forward that the role of the Internet in different regions varied greatly, promoting economic expansion from the perspective of regional heterogeneity. Using Brazil’s interstate data from 2007 to 2011, Jung [13] proposed that for the economic development of underdeveloped regions in Brazil, the Internet

has played a more significant role. Through empirical research, Chakraborty and Nandi [14] discovered that the contribution of Internet development to economic growth was more prominent in emerging countries than in developed countries. On the contrary, when analyzing differences between regions and provinces in China, Lin *et al.* [15] and Han and Zhu [16] proposed the opposite conclusion from Jung [13], Chakraborty and Nandi [14]. They found that although the broadband penetration rates in central and western parts of China were relatively close, the overall driving effect of the Internet on the economy of underdeveloped western areas was extraordinarily weak. Ye *et al.* [17] pointed out that under the background of big data, the higher the level of economic development was, the greater the Internet transaction volume would be. Jung [13] explained that the backward areas usually had insufficient factor endowment and natural resources shortage. The emergence of the Internet has provided new valuable support for the economic development of these regions. Yet, Han and Zhu [16] held that due to the low level of information application in western China, the role of the Internet in the west region could not be fully exerted.

B. RESEARCH ON THE IMPACT OF THE INTERNET ON ENVIRONMENTAL PERFORMANCE

In the relevant research on how the development of the Internet affects carbon dioxide emissions, Faisal *et al.* [18] proposed that the impact of Internet development on CO₂ emissions presented a non-linear inverted U-shaped relationship, that is, carbon dioxide pollution would be gradually reduced after information and communication technology (ICT) development reached a certain degree. Through an empirical analysis of 59 countries along the route of “Belt and Road,” Danish [19] finally pointed out that the development of ICT could help reduce carbon dioxide emissions. Besides, the interaction between ICT and foreign direct investment also reduced carbon emissions to a large extent. From the angle of empirical analysis of China’s national and regional levels, Li and Song [20] concluded that the development of the Internet could significantly decrease carbon intensity. The development of the Internet industry was a necessary measure to enhance the overall strength of developing countries. Bolla *et al.* [21] suggested that a more comprehensive green network development standard should be set, reducing their carbon footprint. By testing the hypothesis of EKC in Tunisia, Amri *et al.* [22] found that the current level of Internet development in Tunisia did not promote the emission reduction of carbon dioxide but rather helped improve both energy efficiency and resource efficiency.

In the research on whether Internet development can increase energy efficiency, Erdmann and Hilty [23] used scenario analysis to study the effect of Internet development on greenhouse gas emissions, finding that, in most cases, the development of the Internet has reduced greenhouse gas emissions. According to the data from five European manufacturing sectors from 1991 to 2005,

Bernstein and Madlene [24] analyzed the relationship between Internet development investment and power consumption intensity. It was found that “communication technology” would bring about a saving effect on electricity consumption. Simultaneously, “computer and software” would produce a less pronounced impact, and the situation of different sectors was not the same. Sadowsky [25] adopted the dynamic panel model to study the relationship between power consumption and Internet development, represented by network connection, mobile phone, and personal computing in emerging countries, discovering that there was a positive correlation between the two. Ketteni *et al.* [26] stated that investment in energy-saving technologies would improve efficiency while increasing the adjustment costs in the short term.

C. RESEARCH ON GREEN TOTAL FACTOR PRODUCTIVITY

1) CONCEPT AND MEASURE OF GTFP

In 1957, Robert. M. Olow introduced the assumption of technology neutrality and constant returns to scale based on “Cobb-Douglas” production function and referred to the “growth residual value” as technological progress after deducting labor and capital input in economic growth, that is, total factor productivity. Besides, Liu *et al.* [27] and Li [28] put forward that total factor heterogeneity among regions was the root cause of economic growth differences. But in fact, traditional total factor productivity ignored energy and environmental factors and failed to accurately evaluate economic performance and social welfare changes [29]. Some scholars noticed this defect, incorporated energy consumption, and environmental pollution into the traditional total factor productivity accounting framework, and finally named such comprehensive total factor productivity as GTFP.

As for the measurement of GTFP, most scholars adopted non-parametric data envelopment analysis, which had the advantage of not having to set the function form and decompose productivity [30]. Chung *et al.* [31] proposed a directional distance function when measuring the TFP of Swedish pulp mill. Considering environmental factors, pollution emission could be regarded as an undesired output to measure GTFP in this method. To overcome non-zero relaxation caused by a radial angle, Tone [32] established the SBM model based on the relaxation variable. This kind of method was more in line with the actual production. It relaxed the restriction on the radial variation of input-output factors to avoid the angle deviation. Since then, this method has been widely used in measuring total factor productivity. For example, Chen [33] included the carbon dioxide emissions of the industry in the estimation index and used the directional distance function to measure the green TFP of 38 industrial industries. The results showed that the green TFP with carbon dioxide emissions included was much lower than the TFP without pollution emissions considered. Other scholars measured and compared the GTFP of 30 regions and 34 industrial industries in China, respectively, [34], [35].

2) RESEARCH ON THE INFLUENCE OF THE INTERNET ON GTFP

In recent years, the relationship between the Internet and productivity has attracted complete attention from scholars. Guo and Luo [36] raised the conclusion that “computers do not help to improve productivity,” discussed by Solow, which did not accord with the reality of China. On the contrary, the Internet with the computer as the main terminal has played a vital role in raising China’s total factor productivity. Taking the equipment manufacturing industry as an example, Xiao [37] believed that the development of the Internet could improve the total factor. According to the empirical analysis of the panel data of ports and cities in China’s Yangtze River Economic Belt, Song and Liu [38], Li and Liu [39] all obtained the impact of Internet development on total factor productivity had regional differences. Most of the existing literature mainly studied the impact of Internet development on TFP, while few studies discussed whether Internet development had a driving effect on green TFP.

3) RESEARCH ON THE INFLUENCE OF HUMAN CAPITAL ON GTFP

As one of the critical determinants of economic and social system development, human capital was a non-negligible factor in “efficiency-oriented” investment [38]. Mannasoo *et al.* [41], Barcenilla *et al.* [42] took the European Union as the research and concluded that human capital could significantly improve total factor productivity. Li *et al.* [43] believed that the imbalance of human capital structure would have a negative impact on total factor productivity in China. After relevant empirical studies on central and eastern European countries and BRICS, Misbah *et al.* [44] proposed that human capital played a crucial role in promoting TFP improvement. Regarding the immigration policies and realities in France, Germany, and the United Kingdom, Fassio *et al.* [45] hold that immigration would boost total factor productivity effectively, especially the transfer of highly educated human capital, which could drive regional development through knowledge sharing. Aiming at the deficiency of research on human capital and GTFP, Zhang and Hu [46] made an empirical analysis of innovative human capital and GTFP in the Yangtze River Delta region of China. The results indicated that due to the “siphon effect” of innovative human capital and the “rebound effect” induced by technological innovation, human capital in this region has not effectively improved GTFP as expected. However, they only discussed the linear relationship between innovative human capital and GTFP. Moreover, the sample of the research was only limited to the innovative human capital in the Yangtze River Delta region of China, which belonged to the most advanced region in China’s economic development, with high quality of economic development and sufficient accumulation of human capital. There was a significant difference between the Yangtze River Delta region and the general situation in China, so the conclusion of this study lacked broad guidance.

4) RESEARCH ON OTHER INFLUENCING FACTORS OF GTFP

On the foundation of incorporating environmental factors into the total factor productivity measurement framework, economists have also carried out many valuable analyses on the factors affecting the efficiency of the green economy under environmental constraints. In addition to the above factors of Internet development and human capital, other factors such as environmental regulation [47], [48], fiscal decentralization [49], factor distortion [50], technological innovation [51], [52], financial development [53], energy conservation and emission reduction policy plans [54], [55] would also affect green TFP in different degrees. Through the years, with the in-depth development of economic globalization, the “One Belt and One Road” initiative has also effectively raised GTFP in provinces along the route of China [56]. Likewise, the construction of the China-Korea Free Trade Area has also improved GTFP in China’s manufacturing industry [57]. The existing literature has laid a solid theoretical foundation for this paper, but there are still three deficiencies. First, the existing literature on Internet development mainly explored its unilateral impact on economic growth or environmental performance. But in fact, in order to boost green economic growth, it is indispensable to reasonably handle the coordination of the connection among the economy, resources, and the environment. Hence, it is urgent to explore the relationship between Internet expansion and GTFP of China; Second, existing studies mostly used single indicators such as Internet penetration rate to represent the level of Internet development, ignoring that indicators in a particular aspect could only reflect the local facts of Internet development, but could not objectively reveal its accurate level; Third, some existing studies have proved that the effect of Internet development on the economic system had multi-dimensional characteristics. Moreover, due to the remarkable regional heterogeneity in China, it is necessary to explore the existence and form of the nonlinear transmission mechanism between Internet development and green economic growth on the strength of the current status of 30 regions. To make up for the above shortcomings, firstly, this paper calculates the comprehensive index of Internet development by projection pursuit method based on the data of 30 regions in China from 2009 to 2017, then calculates GTFP with ML index method based on SBM directional distance function, and finally, briefly analyze the quantitative relationship between variables by panel regression method. As a special economic factor, Internet development can drive the growth of the green economy in different levels of human capital, thus showing a non-linear relationship. Consequently, taking the human capital level as threshold variable, this article adopts the panel regression model to make an empirical analysis on whether there is a threshold effect among Internet development, human capital, and green economic growth and obtains the specific quantitative relationship between the threshold value and variables

III. MEASUREMENT AND ANALYSIS OF THE INTERNET DEVELOPMENT INDEX

A. ESTABLISHMENT OF THE INDICATOR SYSTEM

At present, the government has not disclosed a comprehensive index of informatization of the Internet, so the measurement is facing difficulties and challenges. Instead, most scholars use a single index, such as the number of CN domain names and websites, to estimate the development level of the Internet. The Internet is a relatively complex system engineering. Although the single index above is a vital reflection of the Internet development level, it is certainly not comprehensive and objective. Hence, this paper constructs the comprehensive index measurement system of China’s inter-provincial Internet development from Internet application and output. The index system includes Internet penetration rate, Internet infrastructure construction, Internet development environment. Table 1 shows the detailed measurement system.

B. CONSTRUCTION OF THE EVALUATION MODEL

The projection tracking model can simplify the observation process of high dimensional data. The principle of this model is to find the feature projection of high dimensional variables in low dimensional space by mathematical method. According to the characteristics and advantages of the projection pursuit model, the projection tracking model improved by the accelerated genetic algorithm based on real coding (RAGA-PP), is established to evaluate the inter-provincial Internet development index in this paper. The following is the specific establishment process of the projection pursuit model.

(1) Standardization of sample indicators. Construct the sample set covering each indicator as $\{x^*(i, j) | i=1, 2, \dots, n; j=1, 2, \dots, p\}$, where $x^*(i, j)$ is the j th index value of the sample of i , n and p are the number of samples and indicators, respectively. Since the data has a different dimension and meaning, they are standardized in the following ways:

For the positive indicators:

$$x(i, j) = \frac{x^*(i, j) - x_{\min}(j)}{x_{\max}(j) - x_{\min}(j)} \quad (1)$$

For the inverse indicators:

$$x(i, j) = \frac{x_{\max}(j) - x^*(i, j)}{x_{\max}(j) - x_{\min}(j)} \quad (2)$$

where $x_{\max}(j)$ and $x_{\min}(j)$ are respectively the maximum and minimum values of the j th index, and $x(i, j)$ is the normalization result of the sample index.

(2) Establishment of the projection exponential function $Q(a)$. By projecting p -dimensional data $\{x(i, j) | j=1, 2, \dots, p\}$ into low-dimensional subspaces, the optimal projection direction $a = \{a(1), a(2), a(3), \dots, a(p)\}$ is formed. The value of the optimal projection direction is similar to the weight value, from which the projection value $z(i)$ and the projection function $Q(a)$ can be obtained.

$$z(i) = \sum_{j=1}^P a(j) x(i, j), \quad i=1, 2, \dots, n \quad (3)$$

TABLE 1. The measurement system of China’s Inter-provincial Internet comprehensive development indicators.

Indicator	Indicator explanation	Calculation method	Unit
Internet penetration rate	Reflect interprovincial Internet popularity	Number of broadband Internet access ports	Ten thousand households
Internet infrastructure construction	Estimate the level of inter-provincial optical fiber infrastructure construction	Length of long-distance optical cable lines	Kilometer
Internet development environment	Measure inter-provincial Internet construction capacity and development space	GDP per capita	Yuan (RMB)

$$Q(a) = S_Z D_Z \tag{4}$$

where S_Z is the standard deviation of the projected value $z(i)$, and D_Z is the local density of the expected value $z(i)$.

$$S_Z = \sqrt{\frac{\sum_{i=1}^n (z(i) - E(z))^2}{n - 1}} \tag{5}$$

$$D_Z = \sum_{i=1}^n \sum_{j=1}^n (R - r(i, j)) \times u(R - r(i, j)) \tag{6}$$

where $E(z)$ is the average of the projection value, R is the window radius of the local density, $r(i, j)$ represents the distance between samples, $r(i, j) = |z(i) - z(j)| .u(t)$ is a unit step function. When $t \geq 0$, its function value is 1, and when $t < 0$, the function value is 0.

(3) Optimization of projection index function. For the determined index set, the change in the projection direction a will result in the difference in the projection index function $Q(a)$. On this account, the optimal projection direction can most effectively reflect the characteristics of high - dimensional data. To estimate the optimal projection direction of high dimensional variables, it is necessary to solve the maximization equation of the exponential projection function, that is, the maximization of the objective function:

$$\max Q(a) = S_Z \times D_Z \tag{7}$$

$$s.t. \sum_{j=1}^P a^2(j) = 1 \tag{8}$$

(4) Calculation of Internet development index. Substitute the optimal projection direction a^* obtained through step 3 into equation (7) and (8), the projection value $z^*(i)$ of every region can be calculated. On this basis, the Internet development index of each area is obtained.

Furthermore, when solving the optimal projection direction, to make up for the shortcomings of the projection tracking method, this paper selects the real coding accelerating genetic algorithm (RAGA) to process data, which can significantly enhance the optimization of the algorithm, and better solve the problem of Hamming cliff in binary algorithm efficiently. The primary purpose of the RAGA is to compress the optimization interval of SGA and to reduce algorithm time, thus improving the operation speed and getting the optimal solution faster.

C. ANALYSIS OF INTERNET DEVELOPMENT INDEX

According to the above calculation method, this paper calculates the Internet development indicators of 30 provinces in

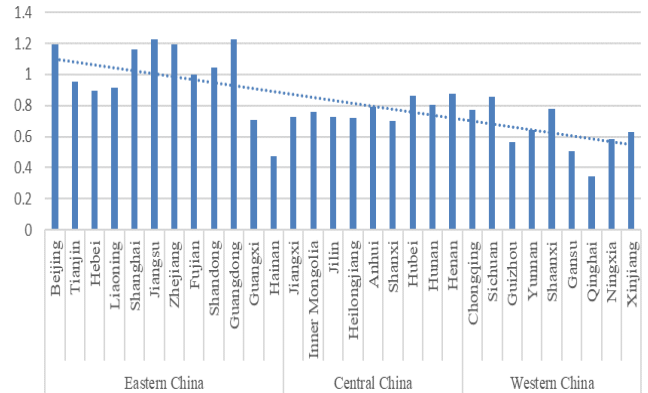


FIGURE 1. Internet development index of each region.

China from 2009 to 2017. Figure.1. shows the average level of each area.

In general, the better the quality of economic development, the higher the score for Internet development. The top five provinces are Jiangsu, Guangdong, Zhejiang, Beijing, and Shanghai, all of which are highly informational, market-oriented, and open. In 2017, the e-commerce transactions in the five provinces totaled 7.13274 trillion, accounting for 54.67 percent of China’s total e-commerce sales. Among them, taking Jiangsu Province as an example, it actively promotes a new generation of information infrastructure. It strives to build an information network where broadband, convergence, sharing, and security coexist. In the first half of 2018, Jiangsu added 10,330 4G base stations and 389,000 mobile base stations, 239,000 of which were 4G base stations, and the construction of a 5G-scale network pilot network has been fully launched.

Meanwhile, the government of Jiangsu province strongly supports the development of Internet enterprises. The world’s most extended single unconnected submarine high-speed fiber-optic cable laid by the Jiangsu Heng Tong Optoelectronics enterprise in the Maldives has allowed the six main islands Maldives to “step” into the 4G era from 2G. Heng Tong company also cooperated with China Telecom to lay ultra-high-speed, ultra-low-loss communication cables on the Hami trunk line in Xinjiang. The “prefabricated fiber bar” independently developed by Heng Tong broke the monopoly of a few optical rod manufacturing giants such as Corning in the United States, Sumitomo in Japan, and Prysmian in Europe, seizing the commanding heights of the industry.

Qinghai province, a multi-ethnic province in western China, is one region with too backward economic development. Its economic development level is far lower than the national average, and its internal economic growth is exceptionally unbalanced. Benefit from the promotion of the “Western Development” strategy, Qinghai Province has made remarkable progress with policy support. Compared with 19,500 yuan in 2000, Qinghai’s per capita GDP increased to 47,700 yuan in 2018. Nonetheless, due to the overall economic development environment and geographical location, the development of the Internet and other high-tech industries in Qinghai province is limited, with ample promotion space. Besides, Hainan province, which ranks second from the bottom, has taken the Internet industry as the first among the province’s 12 key sectors. Its primary strategy is “Internet +” action, including “Internet + Tourism,” “Internet + Agriculture,” “Internet + Transportation,” and “Internet + Circulation,” aiming to boost the integrated development of the Internet and real economy and to enhance the construction of green supply chain. In the meantime, Hainan province has focused on cultivating competitive industrial clusters, such as promoting the creation of “smart ocean” and developing Marine information industrial clusters.

IV. MODEL SETTING AND DATA PROCESSING

A. THE SETTING OF THE ECONOMETRIC MODEL

This paper mainly probes into the mechanism of Internet development affecting GTFP, and in view of this research topic, the panel data regression method is adopted. The econometric model is constructed as follows:

$$GTFP_{it} = \beta_0 + \beta_1 Internet_{it} + \beta_2 Human_{it} + \beta_3 City_{it} + \beta_4 Gov_{it} + \beta_5 Energy_{it} + \beta_6 Open_{it} + \varepsilon_{it} \quad (9)$$

where i represents the province ($i = 1, 2, \dots, 30$), and t represents the year ($t = 2009, 2010, \dots, 2017$). $GTFP_{it}$ indicates the green total factor productivity level of the region, $Internet_{it}$ indicates Internet development index, $Human_{it}$ measures the degree of human capital accumulation, $City_{it}$ expresses urbanization level, Gov_{it} shows the degree of government intervention, $Energy_{it}$ represents energy intensity, $Open_{it}$ describes external dependence, $\beta_0 - \beta_5, \beta_6$ are the coefficients to be estimated respectively, and ε_{it} is the error term.

B. DATA PROCESSING AND INDICATOR DESCRIPTION

The entry point of this paper is the Internet comprehensive development level index. Since the Internet indicators and data information publicly disclosed by China Internet Network Information Center (CNNIC) has been more comprehensive and abundant since 2009, this paper selects 2009 as the sample base period. The data of explanatory variables are all downloaded from relevant yearbooks of The National Bureau of Statistics. At present, only the data of 2017 have been fully counted, and some data of 2018 have not been

published yet. As a result, the research sample period of this paper is set from 2009 to 2017. From the perspective of China’s regions, 30 regions in mainland China are selected as research samples (there is apparent lack of data in Hong Kong, Macao and Taiwan, and Tibet Autonomous Region of China). The sample data processed in this paper are partly from the *Statistical Report on China’s Internet Development*, *China’s Statistical Yearbook on Population and Employment*, *China’s Statistical Yearbook*, *China’s Statistical Energy Yearbook*, *China’s Environmental Statistical Yearbook*, and the *Annual Database by Province* on the website of the National Bureau of Statistics. To ensure the accuracy and credibility of the estimate, this paper set 2009 as the base period. Through GDP index, consumer price index, and fixed asset investment price index, the price of all monetary quantities is adjusted to obtain a comparable price. Simultaneously, for fear of heteroscedasticity and multicollinearity, the related variables are treated with logarithm.

The specific description of related variables is as follows:

(1) Green total factor productivity (*GTFP*). In this paper, *GTFP* is used to represent regional GTFP. Regarding the measurement of GTFP, Chung *et al.* proposed the model of DDF and constructed the Malmquist-Luenberger (ML) index as an extension of the Malmquist index. This method considers both the increase of expected output and the decrease from non-expected production. Meanwhile, the directional distance function of SBM can comprehensively consider the relationship among inputs, outputs, and pollution, thus solving the slack problem in efficiency evaluation. As a result, this paper applies the ML index method with the foundation of the SBM directional distance function in the calculation of *GTFP*. In the detailed calculation process, each region is considered as a decision-making unit, with labor, capital, and energy input as input variables, actual total output as the expected output, and carbon dioxide emissions and environmental pollution emissions as the undesired output. In the past, scholars did not consider resource input when calculating TFP. However, in the measurement of green TFP, the resource input is regarded as the primary source of undesired output. Considering environmental factors, scholars usually incorporate it into the measurement framework to calculate the total factor productivity more accurately.

The ML productivity index from period t to $t + 1$ can be expressed as:

$$ML_t^{t+1} = \left[\frac{1 + \vec{D}_0^t(x^t, y^t, z^t, g^t,)}{1 + \vec{D}_0^t(x^{t+1}, y^{t+1}, z^{t+1}, g^{t+1},)} \times \frac{1 + \vec{D}_0^{t+1}(x^t, y^t, z^t, g^t,)}{1 + \vec{D}_0^{t+1}(x^{t+1}, y^{t+1}, z^{t+1}, g^{t+1},)} \right]^{\frac{1}{2}} \quad (10)$$

The ML productivity index reflects the growth rate of GTFP from period t to period $t + 1$. Therefore, this paper sets the GTFP value in the base period (2009) as one and multiples the measured ML index with it to figure out the GTFP level of different regions from 2010 to 2017.

This article uses the local employment numbers, capital stock, and total energy consumption as the indicators of labor inputs, capital inputs, and energy inputs, respectively; The expected output is the GDP of each region adjusted for the base period of 2009; The undesired output is the composite index of CO₂ emission and environmental pollution. Among them, carbon dioxide emissions are calculated according to IPCC guidelines. Furthermore, different from the existing literature, which only adopts one or several environmental pollution emission indicators, in this study, the entropy method is used to estimate the unexpected output of environmental pollution emissions by integrating industrial wastewater discharge, industrial waste gas discharge, and industrial stable waste discharge into the aggregative index of environmental pollution.

(2) Internet development index (*Internet*). In this paper, the RAGA-PP method is adopted to estimate Internet development in various regions.

(3) Human capital accumulation (*Human*). Human capital can not only effectively improve the region's capacity for high-quality development but also can enhance the awareness of environmental protection of the local people, thus exerting an impact on the region's green development level. Drawing on a series of cross-country comparative studies on education and combining the setting of China's education years, this article takes the proportion of the labor force with different education levels published in the China Population and Employment Statistics Yearbook as the weight to calculate the average education level of the labor force in each region. The level of human capital accumulation is obtained. To calculate the average years of education in each region, we set the years of education for different levels of education: 6 years for elementary school, 9 years for junior high school, 12 years for high school, and 16 years for junior college and above. Then, taking the proportion of each education level in the population as the weight, we figure out the average years of schooling of each region. In line with the availability of data in the statistical data, this paper also calculates the average years of education of the population aged six years and above. The specific calculation formula is as follows:

$$\begin{aligned} Human = & primary * 6 + junior * 9 \\ & + senior * 12 + college * 16 \end{aligned} \quad (11)$$

where *Human* is the human capital level of the region. *primary*, *junior*, *senior*, and *college* respectively represent the proportion of residents with elementary, junior high school, high school, and college education and above in the population over six years old.

Based on the existing studies, this paper also sets control variables such as the urbanization level, the government intervention degree, energy intensity, and external dependence.

First, the urbanization level (*City*). Urbanization is accompanied by the accumulation of population and factors, whose influence on economic development is uncertain. On the one hand, the urbanization process is accompanied by the

concentration of capital and other factors, which promotes the rational allocation of resources and knowledge overflow, accelerates the technological progress and industrial structure upgrading, and thus promotes GTFP; On the other hand, urbanization is accompanied by massive infrastructure construction, which will bolster the demand for energy-intensive products such as cement and coal, thus exacerbating the environmental pollution. Simultaneously, the concentration of factors brought by urbanization may also produce a congestion effect, which will hinder green development. Hence, the influence of urbanization on GTFP remains inconclusive. In the processing of statistics, the level of regional urbanization is represented by the percentage of permanent urban dwellers in the population.

Second, the degree of government intervention (*Gov*). On the one hand, the government intervenes in the regional economy through finance, such as using tax to support environmental protection enterprises and green technology innovation, thus promoting GTFP. On the other hand, in view of GDP competition and performance evaluation of local officials, the government may blindly increase economic output, ignoring the environmental performance in the short term. In consequence, the impact of government intervention on GTFP is full of uncertainty. This paper uses the proportion of government expenditure to GDP to represent the degree of government intervention.

Third, energy efficiency (*Energy*). It is generally believed that the increase in energy intensity contributes to energy efficiency, thereby reducing total energy consumption, easing environmental pressure caused by economic development, and promoting GTFP. However, in the course of commercial operations, the energy saved by improving energy efficiency may generate more energy demand through the effects of mechanisms such as substitution effects, income effects, and output effects, which eventually results in energy savings being partly or even entirely expended by additional energy consumption, known as the "energy rebound effect." Therefore, no firm conclusions have been drawn about the patterns and outcomes of energy efficiency's impact on GTFP so far. This paper adopts the real GDP per unit of energy consumption to measure energy efficiency.

Fourth, external dependence (*Open*). As for the impact of FDI on environmental pollution, there are two opposing viewpoints in the academic circle: "pollution sanctuary" hypothesis and "pollution halo" hypothesis. The former believes that FDI could damage the host country's environment by diverting highly polluting industries. Simultaneously, the latter holds that foreign direct investment could improve the ecological quality by bringing in environment-friendly technology and cleaning products. Therefore, the direction of FDI's influence on GTFP cannot be determined. This article uses the ratio of foreign direct investment (FDI) to GDP to measure external dependence. The correlation matrix and the descriptive statistics of each variable are shown in Table 2. In light of the test results, most of the variables are correlated at the significance level of 1%. The correlation coefficient

TABLE 2. Correlation matrix and variable statistics.

Variable	<i>GTFP</i>	<i>Internet</i>	<i>Human</i>	<i>City</i>	<i>Gov</i>	<i>Energy</i>	<i>Open</i>
<i>GTFP</i>	1.000						
<i>Internet</i>	0.4118***	1.000					
<i>Human</i>	0.2635***	0.6452***	1.000				
<i>City</i>	0.2979***	0.6477***	0.8301***	1.000			
<i>Gov</i>	-0.3612***	-0.5251***	-0.2885***	-0.3564***	1.000		
<i>Energy</i>	-0.2338**	-0.6240***	-0.4495***	-0.4747***	0.5671***	1.000	
<i>Open</i>	0.2482***	0.3531***	0.5030***	0.6596***	-0.2150**	-0.3980***	1.000
Obs	270	270	270	270	270	270	270
Mean	1.040	0.821	9.075	0.553	0.24	0.908	0.053
Std.Dev	0.088	0.296	1.028	0.13	0.101	0.433	0.058
Min	0.736	0.049	6.764	0.299	0.096	0.294	0.008
Max	1.851	1.58	13.525	0.896	0.639	2.503	0.546

TABLE 3. Estimation results of panel data regression.

Explanatory variables	Parameter estimates	t statistic	Adjoint probability
<i>Internet</i>	0.071793	0.041274	0.083
<i>Human</i>	0.037673	0.012385	0.003
<i>City</i>	0.849129	0.319151	0.008
<i>Gov</i>	-0.74181	0.242346	0.002
<i>Energy</i>	0.289613	0.046273	0.000
<i>Open</i>	0.257934	0.151244	0.089
_cons	0.070496	0.190799	0.712
F statistic	11.53	Hausman test	Chi-Sq.= 53.12 P=0.0000
Adjoint probability (F statistic)	0.000		

between the core variables is small, expressing a direction of action consistent with the previous analysis. For instance, the correlation coefficient between Internet development and China’s green economic growth is 0.4118, which is at the 1% significance level, showing that a good momentum of Internet development will contribute to China’s green economic growth.

C. ANALYSIS OF EMPIRICAL RESULTS

According to the Hausman statistic test, a fixed effect is more effective than a random effect model. Therefore, for the actual effect of the Internet on green development, this study adopts the fixed-effect model and carries out panel data regression analysis. Table 3 shows the regression results. According to the results in Table 3, as a whole, the model has passed the significance test (F statistic is 11.53, and the adjoint probability

is 0.000), indicating that the econometric model is set reasonably. A detailed analysis of the influence of various explanatory variables on green economic development is given below. The Internet has a positive impact on China’s green TFP at a significance level of 10%. For every 1% increase in the Internet development index, GTFP increases by 0.0718%, which is in line with the theoretical analysis in this paper, indicating that in the sample period, the development of the Internet has enhanced China’s GTFP. The reason may be traced back to the fact that the development of the Internet has upgraded the economic development model of China’s traditional manufacturing industry, promoted the efficiency and non-materialized transformation of input factors in production, improved the allocation structure of factor resources, and accelerated the development of intelligent manufacturing and the digital economy. Simultaneously, the technological progress contained in the Internet development not only helps to eliminate redundancy and waste in the production process but also can coordinate with other energy-saving measures of enterprises to improve energy utilization efficiency and thus improve GTFP. Besides, the introduction of the Internet into enterprise production can generate energy-saving effect and improve GTFP utilizing automation of the production process, integration of the production process, and information flow.

Human capital positively affects China’s green economic growth at a significant level of 5%, manifesting that human capital can effectively enhance the GTFP in the sample period. The most important reason is that human capital can provide necessary human support for energy conservation and pollution reduction. In a general way, the introduction of clean energy and environmental technology is bound to green economic growth, and whether these technologies can be effectively absorbed and utilized is not sure. At the same time, a certain amount of human capital accumulation will

contribute to reducing this uncertainty. Besides, the knowledge spillover effect generated by the accumulation of a large amount of high-end human capital is also conducive to the internal technology accumulation and the realization of independent green innovation.

Urbanization positively affects China's green economic growth at a significant level of 5%, showing that urbanization in the sample period has produced an agglomeration effect and promoted intensive economic development. For example, the eastern coastal areas such as Jiangsu, Shanghai, and Guangzhou, with a high level of green economy development, are also the areas with a large degree of urbanization in China. It is easy to find that under the urbanization and income growth, people have higher requirements on environmental quality and influence the government's environmental regulation and enterprises' production behaviour through consumption preference and public opinion pressure, which significantly promotes the green development of China's economy.

Government intervention negatively affects China's green economic expansion at a significance level of 5%, indicating that during the sample period, the government intervention severely hinders the intensive development of China's economy. The possible reason is that the government's economic behaviour interferes with the decisive function of the market in resource allocation, destroys the standard commercial transactions, and results in the mismatch of resources, affecting green economic growth. Simultaneously, it is worth noting that in recent years, the GDP-oriented championship promotion system for officials has contributed to the distorted fiscal expenditure structure of local governments, putting capital construction investment above public services and human capital, which has dramatically restricted the green development of China's economy.

Energy efficiency can significantly promote the development of a green economy in China at a significant level of 1%, revealing that improving energy efficiency is an essential means to accelerate green economic growth. The main reason is that the higher the energy efficiency, the more output per unit of energy consumption, which can not only economize energy use, cutting pollution emissions but also reduce input costs, producing more considerable economic benefits.

At the significance level of 10%, external dependence positively affects the GTFP, which indicates that foreign investment can accelerate the intensive development of the Chinese economy. In detail, FDI import advanced clean production technology for the host country, which forms technology transfer and technology diffusion through a series of effects such as industry demonstration effect, training force, and industry correlation effect of the upstream and downstream industry chain. Foreign direct investment has raised the level of clean technology and energy efficiency in the production of enterprises in the host country. It is a vital force to promote green economic growth.

V. CONSTRUCTION OF THRESHOLD REGRESSION MODEL AND EMPIRICAL ANALYSIS

The previous analysis has confirmed that the driving effect of Internet development on China's green economic growth does exist. However, the effect is multi-dimensional. Its impact may present different characteristics with the different external environment; that is, the relationship between variables is likely non-linear. Notably, the panel threshold regression model is a non-linear econometric model, whose essence is to incorporate the threshold value into the empirical model as an unknown variable, construct the piecewise function of the regression coefficient of the explanatory variable, and then estimate the threshold value internally and the parameters of different threshold intervals. According to the above characteristics, this paper applies the panel threshold regression model to study the non-linear relationship between the Internet and economic expansion. On the grounds of the classical theory of economics and reliable literature, the reasons why this paper studies the threshold effect and the theoretical mechanism of the threshold effect are as follows:

Due to the knowledge-intensive nature of the Internet economy, human capital determines the driving force behind the impact of the network economy. At present, the Internet economy is gradually developing into a platform and integration, putting forward higher requirements for the deepening and integrating human capital, which is crucial to the spread of the network economy. Sufficient human capital reserves can not only provide adequate support for the growth of the Internet economy and improve the technology spillover effect of the Internet economy but also can provide high-quality customers and demands for the growth of the Internet economy. For instance, in Beijing, Shanghai, Hangzhou, and other places where the Internet economy is developing well, many high-level talents have gathered. The close combination of industry, university, and research not merely forms a series of high-end Internet development platforms but also significantly improves the level of green innovation in the region. Similarly, the formation of Silicon Valley in the United States, which is close to world-renowned universities such as Stanford and Berkeley, also confirms this statement. Based on the above analysis, and considering striking differences in the economic development status and higher education levels in various regions of China, this paper holds that at different levels of human capital, Internet development may affect green economic growth in different directions, that is, there is an absolute critical value of human capital. Given the above analysis, the panel threshold regression model is set as follows:

$$GTFP_{it} = \theta + \alpha_1 City_{it} + \alpha_2 Gov_{it} + \alpha_3 Energy_{it} + \alpha_4 Open_{it} + \beta_1 Internet_{it} I(Human_{it} \leq \eta) + \beta_2 Internet_{it} I(Human_{it} > \eta) + u_i + \varepsilon_{it} \quad (12)$$

where $I(\bullet)$ is an indicator function, if there is no threshold effect, the value is 0. Following the numerical relationship

TABLE 4. The test results of the threshold effect.

Threshold	F-value	p-value	Critical Value		
			10%	5%	1%
Single threshold	169.07 ***	0.0000	11.5551	13.6647	15.8502
Double threshold	14.10 **	0.0600	12.4530	14.2779	18.4760
Triple threshold	9.42	0.7200	24.4273	28.1966	33.7150

TABLE 5. Threshold values and confidence intervals.

Model	Threshold Estimators	95% Confidence Intervals
Single threshold	10.6469	[10.5050, 10.6543]
Double threshold	10.9507	[10.9220, 11.0090]

between the threshold variable (human capital) and the threshold value η , the sample can be divided into two intervals, and interval slope values are respectively β_1 and β_2 . The remaining variables are the same as in formula (9).

Homoplastically, on account of the single threshold value model, this paper further considers the case where there are multiple thresholds in the model. The following is the establishment of the double threshold model:

$$\begin{aligned}
 GTFP_{it} = & \theta + \alpha_1 City_{it} + \alpha_2 Gov_{it} + \alpha_3 Energy_{it} \\
 & + \alpha_4 Open_{it} + \beta_1 Internet_{it} I (Human_{it} \leq \eta_1) \\
 & + \beta_2 Internet_{it} I (\eta_1 < Human_{it} \leq \eta_2) \\
 & + \beta_3 Internet_{it} I (Human_{it} > \eta_2) + u_i + \varepsilon_{it} \quad (13)
 \end{aligned}$$

where $\eta_1 < \eta_2$. The calculation process of the double threshold model is similar to that of the single threshold, in which the second threshold is estimated when the first threshold is fixed. The following is the specific empirical analysis of the panel threshold model:

As can be seen from the above table, the $F - value$ is significant in both the single threshold model and the double threshold model. The P-value is less than 0.1, while it is not significant in the triple threshold model ($P - value$ is more significant than 0.1). Therefore, there is a double threshold in the model, as shown in Table 4.

Corresponding to Table 5, according to the threshold model principle, the threshold estimation value is η when LR (likelihood ratio) approaches 0. Figure 2 shows the likelihood ratio functions of the two thresholds of 10.6469 and 10.9507 within the confidence interval of 95%. The lowest point of the LR statistic is the corresponding actual threshold value, and the dashed line indicates the critical value of 7.35. Since the critical value is significantly larger than two threshold values, it can be considered that the above threshold values are genuinely valid.

The panel threshold regression statistics are shown in Table 6. According to the data, the acceleration influence of Internet development on green economic expansion in China

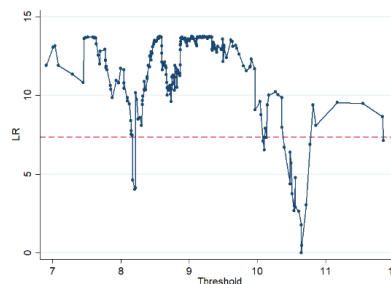


FIGURE 2. The first threshold value.

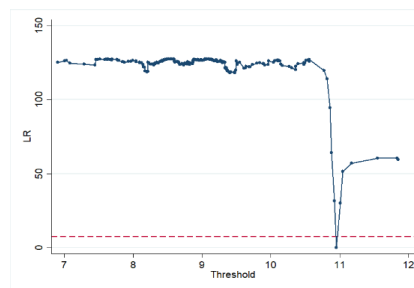


FIGURE 3. The second threshold value.

is not monotonically increasing (or decreasing). The elasticity coefficient is significantly different in various provinces. With the accumulation of human capital from weak to healthy, the effect of Internet development on China’s green economic expansion from negative to positive. When the level of human capital accumulation is less than 10.6469, Internet development has a weak adverse influence on the growth of the green economy; When the human capital accumulation crosses the first threshold value ($10.6469 < Human \leq 10.9507$), the impact of Internet development on the growth of the green economy has a structural change, and the elasticity coefficient changes from negative to positive, which is still not conspicuous; When human capital accumulates across the second threshold, the elasticity coefficient of Internet development for green economic growth gradually increases at the 1% significant value. For every 1% increase in the Internet development index, GTFP will increase by 0.3105%.

In the light of the panel regression results, only when the level of human capital reaches a particular threshold value can the driving effect of Internet development on the green economy be effectively exerted. The reason may be that the development of the Internet requires a large amount of infrastructure construction, which will inevitably generate a certain amount of power consumption and energy consumption. On this account, in areas with insufficient human capital accumulation, the Internet cannot be fully developed to offset adverse environmental externalities nor effectively promote green economic growth. On the contrary, in the regions with sufficient human capital reserves, the agglomeration effect of human capital can effectively encourage the combination of production, education, and research, and promote the adjustment of regional industrial structure through technological innovation and other means, thereby improving the

TABLE 6. Estimation results of model parameters.

Caption	Coef.	Std. Err	t	p > t	95% Conf. Interval	
<i>City</i>	1.9528	0.2631	7.42	0.000	1.4343	2.4712
<i>Gov</i>	-1.0039	0.2007	-5.00	0.000	-1.3993	-0.6085
<i>Energy</i>	0.3175	0.0383	8.30	0.000	0.2421	0.3929
<i>Open</i>	0.0090	0.1266	0.07	0.944	-0.2404	0.2583
<i>Internet(Human ≤ 10.6469)</i>	-0.0204	0.0350	-0.58	0.560	-0.0894	0.0486
<i>Internet(10.6469 < Human ≤ 10.9507)</i>	0.0337	0.0362	0.93	0.353	-0.0377	0.1051
<i>Internet(Human > 10.9507)</i>	0.3105	0.0381	8.16	0.000	0.2355	0.3855
cons	-0.0933	0.1550	-0.60	0.048	-0.3987	0.2121

development level of the green economy. Taking Hangzhou, China as an example, the region's abundant high-end human capital has established a solid foundation for developing large Internet companies such as Alibaba and NetEase. The remarkable growth of the Internet economy has written a new chapter of green progress in Hangzhou. On June 5, 2019, the 48th United Nations World Environment Day Global Home Event was held in Hangzhou; environmental experts from home and abroad came to Hangzhou, enjoying the atmosphere of green development in the economic environment. The high level of Internet development has promoted the construction of the "smart city" in Hangzhou and encouraged personalized policy supporting measures by the government. The comprehensive "greening" of public transportation, the "railing" of urban transport, and the "zero emissions and zero pollution" of pure electric buses have all turned into strong evidence of Hangzhou's determination to green development.

VI. RESEARCH CONCLUSION

For the time being, the Chinese economy has entered a new normal of "three-phase superposition," during which the growth rate, the economic structure, and development impetus all need to be adjusted and reshaped urgently. Under the constraint of limited factor input, it has become an essential link in the economic transformation to promote the transformation of economic development mode from extensive to intensive and improve GTFP. With the rapid development of Internet information technology, Internet development has become an essential factor affecting the low-carbon growth of China's economy and the improvement of GTFP. In this context, based on the panel data of 30 provinces in China from 2009 to 2017, the paper firstly improved the projection pursuit model to measure the Internet development index through an accelerated genetic algorithm (RAGA-PP). This paper comprehensively analyzes the Internet development levels and differences among different regions in China and reveals the "digital divide" among different regions in China. Secondly, this paper constructs the input-output model of GTFP measurement in China. It adapts the ML index method

based on the directional distance function of SBM to measure the GTFP level in various regions of China, thus accurately evaluating the development level and gap of each region. Thirdly, this paper applies the fixed effect model to test the effects of Internet development, human capital, and other variables on GTFP. It then explores the influence relationship between explanatory variables and GTFP from "linear" influence. Finally, in view of the knowledge-intensive characteristics of the Internet economy, this paper brings human capital into the complicated non-linear relationship of the Internet development driving GTFP. It empirically tests the mechanism of action among the three. The main conclusions are as follows:

First, there is a significant imbalance in the development level of the Internet in various regions of China. By and large, the Internet development index presents a similar trend of decline in the "east-central-west" economic development level. In the eastern coastal areas, especially Jiangsu, Guangdong, and other provinces with significant economic strength, the economic growth advantage not only provides critical technical support for the development of the Internet but also for the penetration and popularization of the Internet in various industries, thus producing distinct "Internet +" green economy effect. But in Qinghai, Hainan, and other central and western provinces, the Internet level is relatively backward. To stimulating the potential of the Internet economic effect, these regions should make great efforts in the construction of inclusive Internet and the improvement of the Internet penetration rate.

Second, the development of the Internet has a remarkable positive effect on GTFP by integrating resources and applying energy-saving technologies. Human capital can vigorously boost TFP. Human capital can give a big push to GTFP through knowledge spillover and technology accumulation.; Urbanization has a significant positive promotion effect on GTFP. In urbanization, capital and other factors are concentrated, which improves the intensive development of the regional economy; Energy efficiency positively influences GTFP. By controlling energy factor input, the improvement of energy efficiency and reduction of pollution emission

can produce a significant green economic effect. It should be noted that government intervention generates negative impulsion on GTFP. The resource mismatch and short-term behavior caused by government intervention will, to some extent, hinder the low-carbon development of the regional economy and inhibit the improvement of GTFP.

Third, taking human capital as the threshold variable, Internet development has a pronounced double threshold effect on China's green economic growth. The empirical results manifest that in regions with insufficient human capital accumulation, Internet development cannot promote green economic growth. In contrast, only when regional human capital crosses the threshold can the green spillover effect of Internet development be brought into full play.

APPENDIX

ABBREVIATIONS

<i>GTFP</i>	Green total factor productivity
<i>TFP</i>	Total factor productivity
<i>SARS</i>	Severe acute respiratory syndrome
<i>COVID – 19</i>	Coronavirus disease 2019
<i>ML index</i>	Malmquist-Luenberger index
<i>SBM</i>	Slacks- based Measure
<i>DEA</i>	Data Envelopment Analysis
<i>IPCC</i>	Intergovernmental Panel on Climate Change
<i>Internet</i>	Internet development index
<i>Human</i>	Human capital accumulation
<i>City</i>	Urbanization level
<i>Gov</i>	Government intervention
<i>Energy</i>	Energy efficiency

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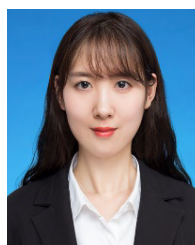
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