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Internet Development and Green Total Factor Productivity: New Evidence of Mediation and Threshold Effects

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Abstract: The strategy of sustainable development is not only a long-term plan for the survival and development of the Chinese nation, but also an inevitable requirement for the coordinated economic and social development of all countries in the world. With the rapid development of new-generation information technology, the Internet may play an even more important role in the implementation of sustainable development strategies. Using China's interprovincial panel data from 2011 to 2020, this paper examines the impact of internet development on green total factor productivity (GTFP) and its mechanism of action using a two-way fixed-effects panel model, a mediation effects model and a threshold effects model. The results show that, firstly, internet development can significantly promote the increase in GTFP, and this conclusion still holds after several robustness tests; secondly, internet development can indirectly promote GTFP through optimizing industrial structure, human capital structure and improving technological innovation; thirdly, based on a single threshold effect of advanced industrial structure, advanced human capital and internet development, the impact of the Internet on GTFP is found to be nonlinear. Finally, our study provides policy recommendations for the promotion of green total factor productivity in China.

Keywords: internet development; green total factor productivity; industrial structure upgrading; advanced human capital; technological innovation

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1. Introduction

As China's economy enters a new normal, China is beginning a new stage of development, and economic development is starting to shift from a stage of high-speed growth to a stage of high-quality development. The 2021 Party's 20th Congress report emphasizes that high-quality development is the primary task of building a modern socialist country in all aspects. Green total factor productivity (GTFP) is measured by combining the indicators related to energy consumption and environmental pollution with the traditional total factor productivity accounting, which can measure regional economic development more comprehensively and accurately. It is also consistent with the concept of green development under the new development stage [1]. Green total factor productivity (GTFP) fully considers environmental protection and economic development, and it is an important and comprehensive indicator that reflects a country's sustainable development capability [2]. Therefore, how to improve green total factor productivity has become the focus of attention of scholars and governments from all walks of life.

The "13th Five-Year Plan" puts forward the concept of "Internet+" industry, and China's internet has been vigorously developed. The internet industry has become a key industry under the "13th Five-Year Plan". Compared with the previous five-year plan, references to internet industry mentioned in the "14th Five-Year Plan" were scaled down. However, the development priorities of the "14th Five-Year Plan", such as the digital economy, cloud computing and other emerging technologies, are still based on the Internet.

According to the "50th Statistical Report on China's Internet Development", released in 2022, by June 2022, the number of China's internet users reached 1.051 billion, with an internet penetration rate of 74.4%. The report shows that internet basic resources, as well as information infrastructure construction, have been further strengthened. Additionally, the quantity of internet users has been further increased and internet applications are also in continuous development. With the rapid development of cloud computing, big data, mobile internet and other next-generation network information technologies, the development of the Internet will play a greater role in promoting sustainable economic development [3]. The embedding of the Internet in the zeitgeist has brought new opportunities for green total factor productivity enhancement. Compared with traditional technologies, the Internet has unique characteristics of rapidity, comprehensiveness, and penetration in information dissemination. These can be used to organize the optimal allocation and reorganization of production factors in the region [4]. On the other hand, the Internet can lower transaction costs, reduce intermediate links and speed up transactions. Thus, it promotes increased productivity in manufacturing, upgraded consumption, and accelerated export trade and business model innovation [5]. In addition, the use of digital technologies such as the Internet may amplify the effects of traditional technologies [6].

Can internet development promote green total factor productivity, and what is the transmission mechanism behind this process? What are the characteristics of the promotion effect of internet development on the green total factor productivity? In the era of digital economy, the search for a new driving force for high-quality economic development and the full release of its development potential are the focus of current economic development. The answers to these questions are helpful for objectively measuring the impact of internet development on green total factor productivity and for accurately identifying the relationship between internet development and green total factor productivity. They are important for formulating economic policies that give full play to the driving role of internet development in China's high-quality economic development. In view of this, this paper aimed, on the one hand, to explore the transmission path between internet development and green total factor productivity. On the other hand, it aimed to reveal the nonlinear effect of internet development on green total factor productivity. The novelty of this paper lies in the more comprehensive and in-depth study of the direct and indirect impacts of the Internet on green total factor productivity than seen in the previous literature. This paper not only takes industrial structure upgrading and technological innovation as intermediary variables, but it also includes human capital structure in the analysis of intermediary effects, which broadens its research horizons. In addition, based on industrial structure upgrading, human capital upgrading and internet development, this paper analyzes the characteristics of the nonlinear impact of internet development on green total factor productivity. To solve the above problems, this paper investigates the relationship between internet development and green total factor productivity based on China's 2011–2020 interprovincial panel data using a two-way fixed-effects model, a mediation effects model and a threshold effects model.

The structure of this paper is as follows: Section 2 reviews the existing research literature and presents the research hypotheses of this paper, Section 3 provides the data and model construction of this paper, Sections 4 and 5 analyze the results of the empirical tests, and Section 6 provides the research conclusions and policy recommendations.

2. Literature Review and Research Hypothesis

2.1. Literature Review

From the existing literature, studies closely related to this paper can be categorized into the following three areas:

2.1.1. Internet Development

The studies on the Internet in the literature have focused on industrial structure upgrading, regional innovation capacity and economic growth. Yu et al. selected data

from listed companies from 2011 to 2021 as a research sample and explored the impact of industrial internet platforms on the green innovation performance of enterprises [7]. The results of the study showed that the industrial internet platform significantly improves the green innovation performance of enterprises. Liu et al. studied the impact of internet development on the level of green innovation and the mechanisms of impact [8]. They found that the development of the Internet mainly promotes the regional level of green innovation by reducing the cost of transactions, improving the ability of technology research and development, and strengthening the level of external hyper-views; subsequently, Zhang et al. used the double-difference model (DID) and propensity score matching method (PSM) to study the impact of internet use on enterprise innovation [9]. They found that internet use can significantly improve the innovation level of China's manufacturing exporters. Pisano et al. argue that mobile internet technologies enhance personalization and precision in traditional service industries [10]; Liou et al. found that internet development can promote the transformation and upgrading of industrial structures [11]. Koutroumpis et al. used data from 15 EU countries from 2003 to 2006 in their research and found that the Internet can significantly promote economic growth [12]; Li et al. found that internet development can significantly promote regional economic growth [13].

2.1.2. Total Factor Productivity

In the context of the new development stage, the question of how to promote green total factor productivity growth is the focus of scholars and governments. In recent years a large number of scholars have studied the impact of hot issues such as digital economy, digital finance, human capital, and government policies on total factor productivity.

Digital economy: Yang et al. showed that the digital economy affects total factor productivity through two channels: human capital investment and industrial structure upgrading. In addition, there is also a spatial spillover effect of the development of the digital economy that helps to improve total factor productivity in neighboring regions [14]. Guo et al. found that the digital economy can promote high-quality economic development through two major mechanisms: improving human capital and promoting green technological innovation [15]. Pan found that there is a positive nonlinear effect of the digital economy and upgrading total factor productivity. This suggests that the digital economy is an innovative driver of total factor productivity enhancement and sustainable development [16].

Digital inclusive finance: Digital inclusive finance, as a major part of the digital economy, has also been studied by many scholars for its impact on GTFP. Yu et al. studied the impact of digital finance on GTFP and its mechanism of action from a dynamic perspective. The results show that digital finance can promote GTFP through the effects of technological innovation and upgrading the industrial structure [17]. Xiao et al. used interprovincial panel data from 2011–2019 and found that digital financial inclusion significantly contributed to the increase in total factor productivity in agriculture [18]; however, the opposite conclusion was also reached by other studies. Chen et al. used data of listed companies from 2011–2020 and the digital financial index to investigate the impact of digital financial inclusion on total factor productivity. They found that digital financial inclusion does not contribute significantly to the total factor productivity of listed companies [19].

Human capital: Li et al. found that human capital significantly contributes to GTFP and that high levels of human capital contribute more to GTFP than low and medium levels of human capital [20]. Benhabib and Spiegel found that total factor productivity depends on human capital accumulation [21]. Yao et al. found that the increase in innovative human capital significantly contributes to green TFP, and that the effect on green TFP tends to have a decreasing marginal effect [22].

Government policies: Working from the perspective of the innovation model selection effect of environmental policies, Zhang et al. analyzed the reasons for the slowdown of GTFP growth in China. The results showed that there is heterogeneity in the different incentive effects of environmental policies on innovation and thus on GTFP [23]. Liu

et al. investigated the relationship between policy adjustments in SO_2 emission charges and urban GTFP growth. They found that increasing SO_2 emission charges can reduce emissions and promote GTFP [24]. Guo et al. used a DID model to investigate the impact of energy consumption right trading policies on the efficiency of urban green development. The results showed that energy consumption right trading policies contribute significantly to the efficiency of urban green development [25].

2.1.3. Internet Development and Total Factor Productivity

The Internet, as an important component of the digital economy, is the driving force behind the development of the digital economy and has an important impact on China's high-quality economic development. The available literature on the research results of the Internet's impact on total factor productivity can be divided into three themes. First, whether internet development can promote GTFP growth. Drawing on data from 30 Chinese provinces from 2006–2018, Wang et al. empirically investigated the impact of the digital economy and energy internet on green economic growth using the spatial dynamic Durbin model. The study found that the energy internet and digital economy can significantly promote total factor productivity, and that their interaction term has a positive impact on total factor productivity [26]. Li et al. used China's interprovincial panel data from 2009–2017 and found, among other things, that internet development has a positive effect on GTFP. In addition, there is a double threshold effect of human capital [27]. Secondly, the impact of internet development on total factor productivity is studied from different dimensions based on the total factor productivity decomposition perspective. Based on China's interprovincial panel data from 2002 to 2014, Guo et al. found that the Internet can significantly promote technological progress but has a suppressive effect on China's technical efficiency [28]. However, some scholars have reached the opposite conclusion. Based on the decomposition of GTFP, Liu et al. found that the development of the Internet promotes green technological efficiency but inhibits green technological progress, and in general has a promoting effect on GTFP [29]. Third, the mechanism of the impact of internet development on GTFP and the spillover effects are studied. Fang et al. found a positive effect of internet development and entrepreneurship on total factor productivity. Furthermore, there is a significant spatial spillover effect between internet development, entrepreneurship and GTFP [30]. Using interprovincial panel data in China from 2006–2017, Wu et al. found that internet development can promote total factor productivity by alleviating resource mismatch, promoting industrial structure upgrading, and enhancing regional innovation capacity [31].

In studying the relationship between internet development and GTFP, some scholars have used the spatial Durbin model to study the spatial spillover effect. This can be used to analyze the impact of internet development on GTFP in neighboring regions [30,31]. Some other scholars have used the interaction term to study the impact of the interaction between internet development and other variables on GTFP [26]; in addition, there are also scholars who have used the moderating effect model to study the impact of the Internet on GTFP [29]. The moderating effects model can analyze whether the impact of internet development on GTFP is affected by other factors. However, none of the above models can analyze the mechanism of the impact of internet development on GTFP and the characteristics of nonlinear impact. In order to analyze the transmission mechanism, it is necessary to use the mediation effects model. Currently, the mediation effect test includes the traditional three-step method, bootstrap test and Sobel test. This paper adopts the mediation effect test proposed by Wen et al. [32]. This method combines the traditional three-step method with the bootstrap test, which can overcome the defects of the traditional three-step method. In order to analyze the nonlinear impact effect, it is necessary to use the threshold effects model, which does not need to give the form of the nonlinear equation. The threshold value and its number are completely endogenously determined by the sample data.

Overall, the existing literature provides a theoretical basis for studying the relationship between internet development and GTFP, but there are still some shortcomings that

need to be improved. First, scholars have conducted fewer studies on the effects of the promotion of the Internet on GTFP. Most scholars focus on the digital economy and do little research on the internet. Second, existing research focuses on the spatial spillover effect of internet development on GTFP, and less on the impact of internet development on GTFP. In addition, there is a lack of research on the threshold effect of the mechanism of influence. Testing the threshold effect of the influencing mechanism would be useful in illustrating that regions should pay attention to phasing when increasing GTFP. Third, the existing literature lacks research on the relationship between internet development, human capital structure and GTFP. Only a few scholars have included human capital in their analysis, but they also use years of education per capita as a measure, which cannot measure the quality of human capital. Therefore, the marginal contribution of this study is threefold. Firstly, compared with the existing literature, this paper more comprehensively and extensively researches the impact of internet development on GTFP. Specifically, this paper analyzes the impact of internet development on GTFP from the three aspects of industrial structure upgrading, human capital advancement and technological innovation, thus deepening the existing literature and filling in the corresponding gaps. Second, this paper further analyzes the nonlinear impact effect of internet development on GTFP. Based on a threshold effect analysis of advanced industrial institutions, advanced human capital and internet development, our study finds that the impact of internet development on GTFP is characterized by increasing marginal effects. Third, this paper incorporates the Internet, human capital structure and GTFP into a unified analytical framework, providing a new perspective for improving GTFP. Unlike the previous literature, this paper analyzes a new path for internet development to influence GTFP by using human capital advanced as a mediating variable. The results show that human capital structure plays a masking effect.

2.2. Research Hypothesis

2.2.1. Internet Development and Green Total Factor Productivity Improvement

As an important part of the digital economy, the Internet has the characteristics of innovation, greenness and sharing. It can promote GTFP by improving the efficiency of factor allocation, facilitating information sharing, establishing public service platforms, and upgrading environmental regulations. First, compared with traditional technologies, the Internet has unique rapidity, comprehensiveness, and penetration in information dissemination. Thus, it can alleviate the information asymmetry problem in factor markets and trigger the optimal allocation and reorganization of production factors in the region [4]. The development of the Internet has largely reduced transaction costs and increased productivity [33]. The development of the Internet has broken down barriers to information transmission, accelerated the flow of data and communication, and reduced information asymmetry, thus improving the efficiency of factor allocation [34]. Second, the Internet has given rise to the "connected economy", which facilitates cross-sectoral and cross-industry data sharing, information interaction, and technological competition and spillovers. It can thus further promote cross-industry and cross-sectoral research and innovation and innovate production and management models [35]. In addition, the Internet provides a platform for product consumers and producers to communicate. This allows consumers to express their views and enterprises to target production reforms in order to improve innovation and production levels. Specifically, the Internet can facilitate GTFP development through the creation of databases and public service platforms. With the development of the Internet, the internet-mediated sharing economy is gradually emerging and developing. Individuals can share resources by providing idle resources to users who need to access public service platforms through the Internet [27]. Finally, the development of the Internet will reduce the cost of corporate regulation of pollution emissions, thus reducing corporate pollution behavior. With the popularization of internet technology, the timeliness, extensiveness and intertemporal nature of information disseminated through the Internet have enriched the environmental participation of social subjects. As a result, enterprises' excessive emissions are more easily disclosed and social opinions are more easily formed.

This, to a certain extent, makes up for the lack of government supervision, thus promoting pollution reduction [36]. Erdmann and Hilty applied a scenario analysis method and found clear evidence that information and communication technology can be effective at reducing greenhouse gas emissions in most scenarios [37]. Based on the above analysis, the following hypothesis is proposed in this paper:

Hypothesis 1 (H1). *Internet development can significantly contribute to green total factor productivity improvement*.

2.2.2. Mechanisms of the Impact of the Internet on Green Total Factor Productivity

First, the Internet can promote GTFP enhancement by facilitating an advanced industrial structure. The upgrading of industrial structure includes two dimensions: an advanced industrial structure and a rationalized industrial structure. The advanced industrial structure mainly refers to the developmental trend of industrial structure from low-end to high-end and from low efficiency to high efficiency [38]. The wide application of internet information technology has given rise to new industries, such as e-commerce and mobile payment. The proportion of emerging industries has further increased. Meanwhile, because of the permeability of internet information technology, traditional industries have reduced production costs through the transformation and upgrading of internet technology, thus promoting advanced industrial structures.

The rationalization of industrial structure refers to the degree of proportional balance, correlation and coordination among industries. Internet development mainly influences industrial structure rationalization by optimizing the resource allocation mechanism [11]. The Internet can improve factor mismatch by reducing transaction costs and easing information asymmetry. It can promote the transfer of production factors from inefficient to efficient sectors, optimize the efficiency of factor resource allocation and make full use of factors. Therefore, it is conducive to the rationalization of industrial structure. In the process of industrial structural change, technological innovation can transform the means of production, eliminating or transforming old industries to create new ones. The productive efficiency of input factors changes from quantitative to qualitative, thus generating a "structural dividend" that promotes sustainable economic growth [39].

In addition, the Internet can also influence GTFP by enhancing the quality of human capital. With the further development of digital information technology, such as the Internet, the Internet has gradually penetrated into various industries, and the country's demand for innovative talents has further increased. On the one hand, the integration of various industries with the Internet and other information technologies drives the continuous transformation and upgrading of traditional industries. As a result, it further increases the demand for highly skilled personnel. With the development of the Internet, high-quality human capital is essential for the introduction, improvement and promotion of various new technologies. This will inevitably promote the evolution of human capital structures to an advanced level [40]. On the other hand, information technology, represented by the Internet, has provided abundant educational resources and convenient channels for knowledge acquisition. This has lowered the cost of knowledge acquisition and made the equalization of education possible, further contributing to the increase in the stock of human capital and the advanced structure of human capital in society as a whole. As the level of human capital continues to rise, it will further influence the level of technology introduction and, thus, the regional GTFP [38].

Finally, the Internet can promote GTFP in each region by facilitating technological innovation in each region. The Internet, as a rapidly developing information technology, is characterized by connectivity, publicness, and permeability. The Internet can overcome the temporal and spatial limitations of information transmission and enable mobile collection, integration and analysis of scattered mass data. At the same time, R&D personnel can obtain accelerated dissemination and exchange information more rapidly and comprehensively. This facilitates the sharing of information throughout society which, in turn, drives

technological innovation [41]. In addition, the Internet is able to integrate and share disorganized knowledge in cyberspace. Thus, R&D personnel will not only be hit by knowledge spillover from time to time but will also be able to access the required knowledge through search engines, which significantly improves the innovation efficiency of R&D personnel [42]. From the perspective of the innovation system, technological innovation reduces energy consumption outflows through systemic transformation, which then improves total factor productivity overall [43]. According to the classical model and the endogenous development prototype, a realizable economy relies primarily on technological progress, which is usually quantified by growth in total factor productivity [44]. Based on the above analysis, this paper proposes the following hypotheses:

Hypothesis 2 (H2). *Internet development indirectly contributes to the improvement of urban green total factor productivity by optimizing industrial structure, human capital structure and enhancing technological innovation.*

Hypothesis 3a (H3a). *The Internet may affect green total factor productivity through indirect means based on the threshold effects of upgrading industrial structure and advanced human capital.*

2.2.3. Internet Development for Green Total Factor Productivity Improvement Has a Nonlinear Effect

According to Metcalfe's Law, the value of the Internet grows at the rate of the square of the number of users. Thus, the impact of the Internet on GTFP may also be nonlinear. The Internet has a significant network effect [45]. With the further application of internet network technology, transaction costs among sectors are further reduced and the benefits that participants derive from transactions will continue to increase. Gruber and Koutroumpis pointed out that low-income countries with lower levels of internet development benefit less from digital technologies than high-income countries [46]. Because of the presence of network effects, the value of the Internet will continue to increase as new internet users continue to join, and its contribution to the economy will continue to grow [28]. Therefore, the impact of internet development on GTFP may be characterized by "increasing marginal effects". Based on the above analysis, the following hypothesis is proposed in this paper:

Hypothesis 3b (H3b). *The impact of internet development on green total factor productivity is nonlinear in the sense of "increasing marginal effects".*

3. Data and Model Construction

3.1. Variable Setting

3.1.1. Explained Variable

The explained variable in this paper is the green total factor productivity (GTFP) of each province. GTFP, which incorporates environmental pollution factors and energy factors into the analysis, is a further enrichment and expansion of the metric of traditional total factor productivity. It can reflect the quality of economic development more scientifically and accurately. There are many methods of calculating GTFP, including DEA, SFA, SBM–DEA, and the production function method. The SBM model can tune the efficiency value measurement of an ineffective decision-making unit to the current target and improve the strong effective target value relaxation. This overcomes the defects of traditional DEA. In addition, the superefficient SBM model further overcomes the defect that the efficiency value of SBM model can only be within [0, 1]. Therefore, this paper adopted the superefficient SBM model based on nondesired output [47] and the global Malmquist production function index to measure urban GTFP based on the base period of 2011. The GML index calculated according to this method does not refer to GTFP, but to the degree of change in GTFP compared to the previous period. If the GML index is greater than 1, this means that the GTFP has increased compared to the previous year; if the GML index is less than 1, this means that the GTFP has decreased compared to the previous year; and if the GML index

is equal to 1, this means that the GTFP has remained unchanged compared to the previous year. By setting the GTFP in 2011 to 1 and multiplying the GML index for each year on this basis, we can calculate the GTFP for each year from 2011 to 2020.

The indicators include both inputs and outputs. The input elements include labor inputs, capital inputs and energy inputs. Labor inputs are measured by the number of employed persons per year and capital inputs are measured by the capital stock of each province. This paper adopted the perpetual inventory method proposed by Shan. Using the gross fixed capital formation and the fixed asset investment price index from the base period of 2000, it is calculated as follows: $K_{it} = K_{i(t-1)}(1 - \sigma_{it}) + I_{it}$, where I_{it} represents the total fixed asset formation in each province at a constant price in 2000, σ_{it} represents the depreciation rate, and K_{it} represents the capital stock of province i in year t. Energy input is measured by the total energy consumption calculated in tons of coal [48].

Outputs include desired and nondesired outputs. Desired outputs are measured by the actual GDP of each province, calculated using 2000 as the base period. Nondesired outputs are measured by the industrial "three wastes" of each province, i.e., industrial wastewater, industrial sulfur dioxide and industrial soot emissions.

3.1.2. Core Explanatory Variable

The core explanatory variable of this paper is internet development. Most of the existing literature for measuring the level of internet development uses the internet penetration rate as a measurement indicator. In this paper, with reference to data availability and drawing on Huang et al.'s approach, four dimensions of indicators are selected: internet-related employment situation, internet-industry-related output, mobile phone penetration rate, and internet penetration rate [49]. Among them, internet-related employment is measured using the proportion of employees in the computer service and software industry to the number of employees in urban units; internet-related output is measured using the total telecommunication services per capita; cell phone penetration is measured using the number of cell phones owned per one hundred people; and internet penetration is measured using the number of internet broadband access users per hundred people. This paper used the entropy weight method to construct the internet development index. The following Table 1 shows the index system for constructing the internet development index:

Table 1. Internet development level indicator system construction.

Tier 1 Indicators	Secondary Indicators	Indicator Properties
Internet-related practitioners	The proportion of employees in software and computer services as employees in urban units	+
Internet-related outputs	Total telecom business per capita (CNY 10,000)	+
Cell phone penetration rate	Number of cell phones per 100 people (parts)	+
Internet penetration rate	Number of internet broadband access subscribers in 100 people (households)	+

Note: "+" means the indicator is positive.

3.1.3. Mediating Variables

The first value under consideration is industrial structure upgrading, which includes two dimensions: industrial structure rationalization (*TS*) and industrial structure upgrading (TC). According to Gan et al., industrial upgrading uses the proportion of value-added tertiary industry output to the value-added secondary industry output as a proxy variable. A larger ratio represents a more advanced industrial structure in a province. Industrial structure rationalization is usually measured using the Taylor index [50]. The larger the Taylor index is, the more irrational the industrial structure will. For the convenience of

observation, the reciprocal of the Taylor index is used as the measure of industrial structure rationalization in this paper. The specific formula is as follows:

$$TL = \sum_i^n \left(\frac{Y_i}{Y}\right) \ln\left(\frac{Y_i}{Y} / \frac{L_i}{L}\right) \tag{1}$$

$$TS = \frac{1}{\sum_i^n \left(\frac{Y_i}{Y}\right) \ln\left(\frac{Y_i}{Y} / \frac{L_i}{L}\right)} \tag{2}$$

where Y_i represents the output value of industry i; L_i represents the number of employed persons in industry i; L represents the number of employed persons in each region; and Y represents the regional GDP. The larger the value of the TL index is, the more reasonable the industrial structure will be.

Second is advanced human capital (Hum). For human capital premiumization, this paper uses the measure designed by Liu et al. to calculate the human capital premiumization index, denoted by Hum [51] as follows:

First, human capital is classified into five categories: illiterate or semiliterate, elementary school, junior high school, senior high school (including secondary school), and post-secondary school, and their weights are calculated separately to form a five-dimensional vector group. $X_1 = (X_{1,1}, X_{1,2}, X_{1,3}, X_{1,4}, X_{1,5})$, where $X_{1,1}, X_{1,2}, X_{1,3}, X_{1,4}, X_{1,5}$ represent elementary school, junior high school, senior high school (including secondary school), and post-secondary school, respectively.

Then, calculate the angle between the human capital vector and the set of basic unit vectors $\theta_j (j = 1, \ldots, 5)$:

$$\theta_j = \arccos\left(\frac{\sum_{i=1}^5 (X_{j,i} * X_{1,i})}{\left(\sum_{i=1}^5 {X_{j,i}}^2\right)^{\frac{1}{2}} \left(\sum_{i=1}^5 {X_{1,i}}^2\right)^{\frac{1}{2}}}\right) \tag{3}$$

Finally, determine the weights of θ_j, and calculate the human capital premiumization index:

$$Hum = \sum_{j=1}^{5} (\theta_j * W_j) \tag{4}$$

where $X_{j,i}$ represents the i-th component of the basic unit vector set X_j $(j = 1, \ldots, 5)$; $X_{1,i}$ represents the i-th component of the human capital space vector X_1; W_j is the weight of θ_j; and the weights of human capital are set to 1, 2, 3, 4, and 5 for illiterate or semiliterate, elementary school, middle school, high school (including secondary school), and post-secondary school, respectively. The higher the value of Hum is, the higher the level of human capital will be.

Third is technological innovation (INN). For technological innovation, this paper uses the number of patents granted per 1000 people as a proxy variable for technological innovation.

3.1.4. Control Variables

Given the existing studies, this study selected the following variables that affect green total factor productivity: level of financial sector development (Fin), government intervention (Gov), level of economic development (GDP), degree of urbanization (lnUR), and level of foreign investment (FDI). Fin is measured using the value added of the financial sector as a share of GDP; Gov is measured using the local government general budget expenditures as a share of GDP; the level of economic development is measured with the logarithm of the real GDP of each region; lnUR is measured using the logarithm of regional urban population density; and FDI is measured using the ratio of the actual amount of foreign direct investment use to regional GDP, where the amount of foreign direct investment use is converted using the annual average exchange rate.

3.2. Data Sources

Because of the unavailability of some data for Tibetan regions and the unavailability of data on internet penetration before 2011, this paper selects panel data for 30 Chinese provinces as the study sample, excluding the Tibetan province from 2011 to 2020. Because of the lack of data on urban density in Beijing in 2020, this paper uses the linear interpolation method to calculate the data. The data used in this paper can be found in the China Energy Statistical Yearbook, China Statistical Yearbook, China Environmental Statistical Yearbook, and the National Bureau of Statistics.

3.3. Methodology

In order to test the hypotheses proposed in the previous section, the following models are designed in this paper, which are a two-way fixed-effects model, mediation effects model and threshold effects model.

3.3.1. Two-Way Fixed-Effects Model

To explore how internet development affects green total factor productivity, the two-way fixed-effects model is constructed as follows:

$$GTFP_{it} = \beta_0 + \beta_1 * INTER_{it} + \mu_t + \sigma_i + \varepsilon_{it} \quad (5)$$

$$GTFP_{it} = \beta_0 + \beta_1 * INTER_{it} + \beta_j Controls_{it} + \mu_t + \sigma_i + \varepsilon_{it} \quad (6)$$

Equation (5) is the regression model of the explanatory variable internet development (INTER) on green total factor productivity (GTFP), and Equation (6) adds control variables to Equation (5), where i and t represent province and year, respectively; GTFP represents the explained variable green total factor productivity; INTER represents the core explanatory variable of this paper; and Controls represents a series of control variables. Controls represents a series of control variables. μ_t and σ_i represent time fixed effects and province fixed effects, respectively. ε_{it} represents the random error term.

3.3.2. Mediation Effects Model

The methods used to test the mediating effect include the stepwise method, the bootstrap method and the Sobel test, among which the most common method for testing the mediating effect is the causal steps approach of Baron and Kenny [52]. However, in terms of the statistical test validity of the mediation effect, the statistical test validity of the bootstrap method is significantly stronger than that of the stepwise method. Even the coefficients of the stepwise regression test are the least effective among the various tests for mediating effects [53,54]. That is, in cases where the mediating effect is present but not strong enough, it is possible that the stepwise regression coefficient is not significant, but that the bootstrap method test results indicate the presence of mediation. Therefore, some scholars call for using the bootstrap method, which has better test validity, to test for mediation effects [55]. In this paper, we use the modified mediation effect test proposed by Wen et al. [32].

The model constructed in this paper is as follows:

$$GTFP_{it} = \beta_0 + \beta_1 * INTER_{it} + \beta_j Controls_{it} + \mu_t + \sigma_i + \varepsilon_{it} \quad (7)$$

$$Z_{it} = \alpha_0 + \alpha_1 * INTER_{it} + \alpha_j Controls_{it} + \mu_t + \sigma_i + \varepsilon_{it} \quad (8)$$

$$GTFP_{it} = \gamma_0 + \gamma_1 * INTER_{it} + \rho * Z_{it} + \gamma_j Controls_{it} + \mu_t + \sigma_i + \varepsilon_{it} \quad (9)$$

where Z represents the mediating variables, including industrial structure upgrading, industrial structure rationalization, human capital advancement and technological innovation.

According to the test for mediating effects by Wen et al. [32], the specific steps are shown in Figure 1:

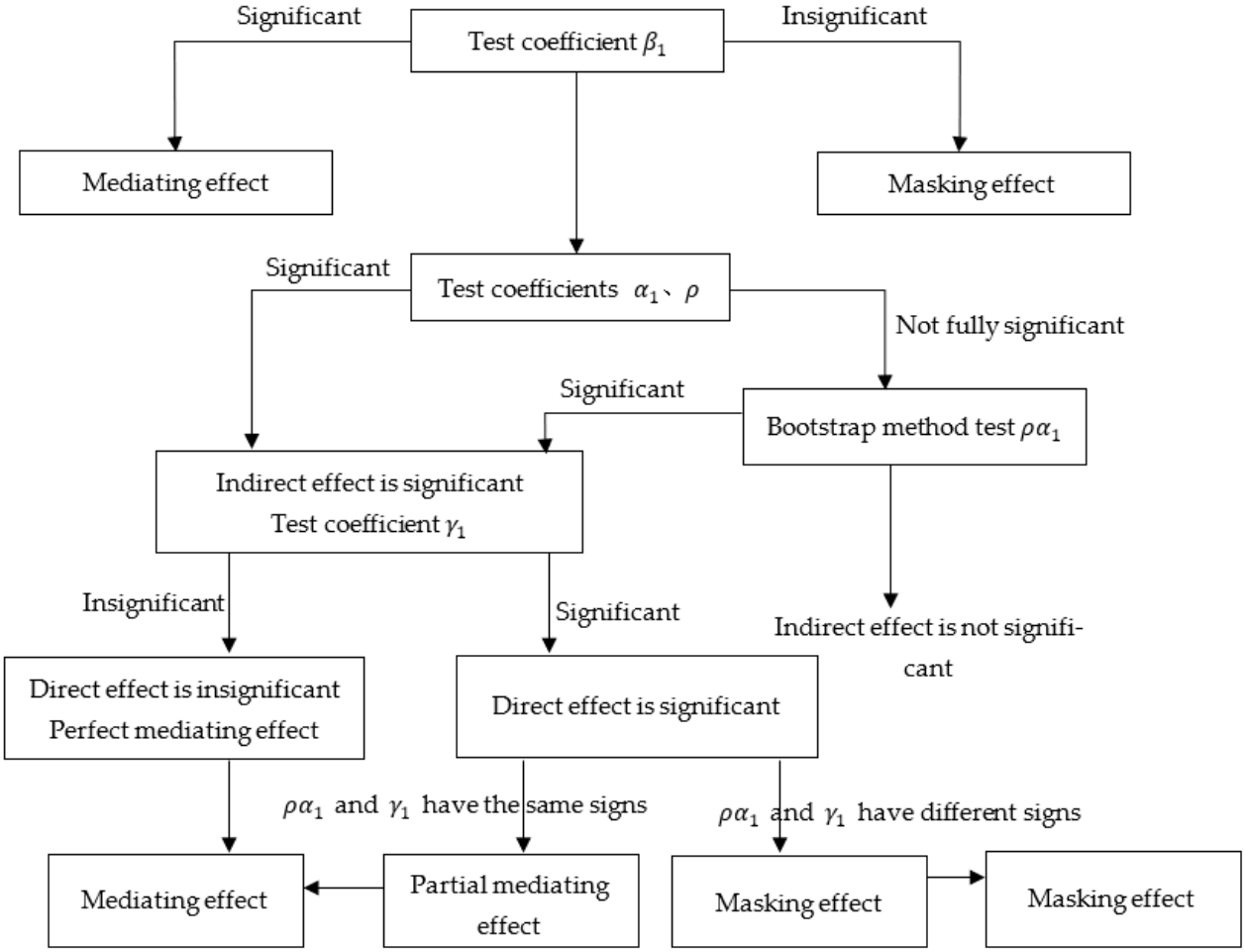

Figure 1. Steps in the mediation effect test.

Step 1: Test the coefficient β_1 of the core explanatory variable internet development in the main regression Equation (7). If β_1 is significant, it is considered a mediating effect; otherwise, it is considered a masking effect. Whether β_1 significant or not, the subsequent test is conducted.

Step 2: Test the coefficient α_1 of internet development in Equation (8) and the coefficient ρ of the mediating variable in Equation (9). If both coefficients are significant, the indirect effect is significant and the researcher can turn to step 4; if at least one of them is not significant, step 3 is performed.

Step 3: Direct test with Bootstrap method. H_0: $\rho\alpha_1 = 0$. If the original hypothesis is rejected, then the indirect effect is significant and the researcher turns to step 4; if the indirect effect is not significant, the mediation effect analysis is stopped.

Step 4: Check the coefficient γ_1 of the mediating variables of Equation (5). If the coefficient γ_1 is not significant, this means that the direct effect is not significant and that it is a fully mediating effect. If it is significant, that is, the direct effect is significant, turn to step 5.

Step 5: Compare the signs of $\rho\alpha_1$ and γ_1. If they are both positive and negative, there is a partial mediation effect, reporting the proportion of the mediator effect to the total effect $\frac{\rho\alpha_1}{\beta_1}$. If the signs are different, it is a masking effect, reporting the absolute value of the ratio of the indirect effect to the direct effect $\left|\frac{\rho\alpha_1}{\gamma_1}\right|$.

3.3.3. Threshold Effects Model

To further test whether internet development has a threshold effect on GTFP improvement and whether the transmission mechanism has a threshold effect, following on from the work of Hansen [56], this paper constructs the threshold effect as follows:

$$GTFP_{it} = \varphi_0 + \varphi_1 * INTER_{it} * I(thre_{it} \leq \tau) + \varphi_2 * INTER_{it} * I(thre_{it} > \tau) + \varphi_j Controls_{it} + \mu_t + \sigma_i + \varepsilon_{it} \quad (10)$$

In Equation (10), *thre* represents the threshold variables, including industrial structure upgrading, internet development, technological innovation and human capital enhancement; $I(.)$ is the indicator function taking the value of 1 or 0, which is 1 if the condition is satisfied, and 0 otherwise; and τ is the threshold value. Here, this paper only takes a single threshold as an example, but this can be expanded to multiple thresholds according to the sample.

4. Empirical Analysis

4.1. Descriptive Statistics

The following table shows the descriptive statistical results for the variables covered in this paper. As can be seen from Table 2, the maximum and minimum values of GTFP among the 30 provinces in China are 2.692 and 0.357, respectively. The mean and median values are 1.174 and 1.111, indicating that there are large differences in GTFP among provinces. The minimum value of internet development index is 0.007 and the maximum value is 0.969, indicating that there is a large gap in internet development among provinces. In addition, the mean value of internet development index of each province is 0.156, which is greater than the median value of 0.096. This suggests that more than half of the provinces have a level of internet development below the national average. At the same time, it can be seen that the human capital structure (Hum), the degree of advanced industrial structure (TC), the rationalization of industrial structure (TS) and the level of technological innovation (INN) vary greatly among provinces. These are in line with China's basic situation of uneven development.

Table 2. Descriptive statistics of the variables.

Variable Name	Average Value	Standard Deviation	Median	Maximum Value	Minimum Value	Sample Size
GTFP	1.174	0.288	1.111	2.692	0.357	300
INTER	0.156	0.144	0.096	0.969	0.007	300
TC	1.324	0.729	1.171	5.244	0.527	300
TS	11.11	13.62	6.119	126.6	1.289	300
Hum	18.29	0.697	18.23	20.93	17.02	300
INN	1.150	1.324	0.599	7.438	0.086	300
lnUR	3.427	0.177	3.431	3.765	2.883	300
Gov	0.264	0.114	0.236	0.758	0.120	300
FDI	0.520	1.977	0.239	34.02	0.0480	300
GDP	9.769	0.886	9.845	11.61	7.160	300
Fin	0.072	0.031	0.067	0.196	0.026	300

4.2. Baseline Regression Analysis

To verify whether Hypothesis 1 holds, this paper incorporated GTFP and internet development index into the two-way fixed-effects model for testing. As shown in Table 3, column (1) represents the regression results of the model where no control variables are added, and column (2) is the regression results when control variables are added. The regression results show that the effect of internet development on GTFP is significantly positive at the 1% level, regardless of whether the control variables are added or not, i.e., the development of internet promotes the improvement of GTFP. Hypothesis 1 is verified.

Table 3. Baseline regression results.

Variables	(1)	(2)
	GTFP	*GTFP*
INTER	3.047 ***	2.519 ***
	(8.09)	(6.49)
lnUR		−0.165
		(−1.15)
Gov		−0.081
		(−0.16)
FDI		−0.005
		(−0.96)
Fin		6.177 ***
		(4.25)
GDP		0.495 ***
		(3.05)
Constant	0.832 ***	−3.497 **
	(24.06)	(−1.99)
Province	Yes	Yes
Year	Yes	Yes
R-squared	0.521	0.568

** and *** indicate significance at the 5% and 1% levels, respectively, and constants indicate intercept terms. Same for below.

4.3. Robustness Tests

Considering the endogeneity issue and the accuracy of the above empirical analysis results, further robustness tests are conducted in this paper to test the accuracy of the regression results.

4.3.1. Substitution of Core Explanatory Variable

In order to test the robustness of the regression results, this paper uses different measures of internet development. Referring to the indicator measurement system of Han et al. [57], this paper selects the four dimensions of internet penetration, internet infrastructure, internet resources and internet development environment. The specific indicators are shown in Table 4. Here, this paper also uses the entropy method to construct the internet development index as a proxy for the core explanatory variable. The regression results are shown in columns (1) and (2) in Table 5. The results show that the impact of internet development on GTFP is significantly positive at the 1% significance level, consistent with the previous findings.

Table 4. Alternative measures of core explanatory variable.

Tier 1 Indicators	Secondary Indicators	Indicator Properties
Internet penetration	Number of internet users per 100 people (households)	+
Internet infrastructure	Number of internet ports (pcs)	+
	Number of domain names per 10,000 people (one per 10,000 people)	+
Internet resource allocation	Total post and telecommunications business (CNY billion)	+
Internet development environment	Per capita disposable income of urban residents (CNY)	+
	GDP per capita (CNY)	+

Note: "+" means the indicator is positive.

Table 5. Robustness tests.

Variables	Substitution of Core Explanatory Variable		Substitution of Explained Variable		Lagged One-Period Explanatory Variable	
	(1) *GTFP*	(2) *GTFP*	(3) *GTFP*	(4) *GTFP*	(5) *GTFP*	(6) *GTFP*
INTER	0.924 ***	0.752 ***	1.593 ***	1.738 ***		
	(3.28)	(2.65)	(6.73)	(7.08)		
L.INTER					4.062 ***	3.341 ***
					(9.05)	(7.33)
lnUR		−0.184		0.239 ***		−0.255 *
		(−1.19)		(2.62)		(−1.74)
Gov		−0.974 *		−0.611 *		−0.178
		(−1.80)		(−1.93)		(−0.37)
FDI		−0.001		−0.002		−0.004
		(−0.20)		(−0.54)		(−0.91)
Fin		8.170 ***		−0.670		6.974 ***
		(5.40)		(−0.73)		(4.65)
GDP		0.540 ***		−0.338 ***		0.481 ***
		(2.98)		(−3.29)		(2.95)
Constant	0.948 ***	−3.642 *	0.912 ***	3.433 ***	0.868 ***	−3.144 *
	(27.74)	(−1.86)	(41.98)	(3.09)	(24.43)	(−1.79)
R-squared	0.424	0.510	0.244	0.309	0.553	0.609
Province	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	300	300	300	300	270	270

*, *** indicate significance at the 10% and 1% levels, respectively.

4.3.2. Substitution of Explained Variable

Considering only the real GDP of the expected outputs, this paper uses the DEA data envelopment method and the Malmquist index to calculate the GTFP in 2011–2020. As in the previous section, 2011 is used as the base period for the calculation. The regression results are shown in columns (3) and (4) in Table 5. As seen from the regression results, the coefficient of the impact of internet development on GTFP was 1.738 at the 1% level of significance. The regression results are relatively robust.

4.3.3. Addressing Endogeneity

Considering that the model may miss variables, as well as the mutual causality between internet development and total factor productivity, this paper adopts the instrumental variable approach and uses internet development with a one-period lag as the instrumental variable. The regression results are shown in columns (5) and (6) in Table 5. The regression results are relatively robust.

5. Further Analysis

5.1. Analysis of Influence Mechanisms

To test the Hypothesis H2, i.e., whether internet development can promote GTFP enhancement through industrial structure upgrading, human capital advancement and technological innovation, this paper further tests the mediating effect. The regression results above tested the main effect, i.e., the first step in the stepwise regression method, which proves that internet development can significantly contribute to GTFP enhancement. Next, this paper analyzes the indirect effects of the mediating variables on this basis.

Table 6 shows the regression results for the second and third steps of the three-step method for different mediating variables, and Table 7 shows the results of further tests for the mediating effects using the bootstrap method with 1000 self-samples.

Table 6. Mediating effect test.

Variables	Advanced Industrial Structure (*TC*)		Rationalization of Industrial Structure (*TS*)		Advanced Human Capital (*Hum*)		Technological Innovation (*INN*)	
	(1) *TC*	(2) *GTFP*	(3) *TS*	(4) *GTFP*	(5) *Hum*	(6) *GTFP*	(7) *INN*	(8) *GTFP*
INTER	1.534 *** (6.55)	2.059 *** (4.98)	56.979 *** (3.39)	2.659 *** (6.73)	2.582 *** (8.14)	2.611 *** (5.99)	8.721 *** (8.45)	1.597 *** (3.79)
TC		0.300 *** (2.94)						
TS				−0.002 * (−1.71)				
Hum						−0.035 (−0.46)		
INN								0.106 *** (4.67)
Constant	2.692 ** (2.54)	−4.304 ** (−2.46)	−36.779 (−0.48)	−3.587 ** (−2.05)	22.706 *** (15.82)	−2.691 (−1.09)	−8.007 * (−1.71)	−2.650 (−1.56)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.891	0.582	0.294	0.573	0.554	0.568	0.687	0.602
Observations	300	300	300	300	300	300	300	300

*, ** and *** indicate significant at the 10%, 5% and 1% levels, respectively.

Table 7. Bootstrap medium effect test.

	Direct Effect	Indirect Effects	95% Confidence Interval	Agency Type
TC	2.059 ***	0.460 *	[0.0829, 1.2237]	Some agents
TS	2.659	−0.140 ***	[−0.3830, 0.054]	Intermediary is not established
Hum	1.652 **	−0.320 **	[−0.7029, −0.0794]	Masking effect
INN	1.597 **	0.922 ***	[0. 3527, 1.769]	Some agents

*, ** and *** indicate significant at the 10%, 5% and 1% levels, respectively.

The coefficient α_1 of internet development in model (8), the coefficient ρ of the mediating variables and the coefficient γ_1 of internet development in model (9) were tested according to the process of testing the mediating effects, as described in the previous section. For the advanced industrial structure (TC), as shown in column (1) in Table 6, the regression coefficient α_1 is significantly positive at the 1% level ($\alpha_1 = 1.534$, $t = 6.55$). And from column (2) in Table 6, the coefficients of the mediating variables ρ and γ_1 are also significantly positive ($\rho = 2.059$, $t = 4.98$; $\gamma_1 = 0.300$, $t = 2.94$). It can be seen that the indirect effects $\rho\alpha_1$ sign has the same value as the direct effect γ_1. The same sign indicates that industrial structure upgrading plays a mediating effect in the effect of internet development on GTFP. And, as shown in the bootstrap test results in the first row of Table 7, the 95% confidence interval is [0.0829, 1.2237], which does not contain 0, and the sign of the direct effect is the same as that of the direct effect. This also proves that industrial structure upgrading plays a partial mediating effect. The partial mediating effects of the advanced industrial structure are shown in Figure 2, with a mediating effect of 18.26%. The possible reason for this is that the proliferation of the use of the Internet can improve the efficiency of the allocation and use of production factors in traditional industries and promote the upgrading of the industrial chain to the middle and high end [11].

For industrial structure rationalization (TS), as shown in columns (3) and (4) in Table 6, the regression coefficient α_1 is significantly positive at the 1% level ($\alpha_1 = 56.979$, $t = 3.39$), and the coefficients of the mediating variables ρ and γ_1 are also significant ($\rho = -1.71$, $t = 2.94$; $\gamma_1 = 2.659$, $t = 6.73$). Because of the indirect effect, the $\rho\alpha_1$ sign is opposite to the direct effect of γ_1, and this indicates that industrial structure rationalization plays a masking effect. However, it can be seen from the results of the bootstrap test in Table 7

that the 95% confidence interval is [−0.3830, 0.054]. Since the confidence interval contains 0, this indicates that industrial structure rationalization does not play a mediating effect. Considering the weak validity of the stepwise regression coefficient test, this paper therefore concludes that there is no mediating effect of industrial structure rationalization.

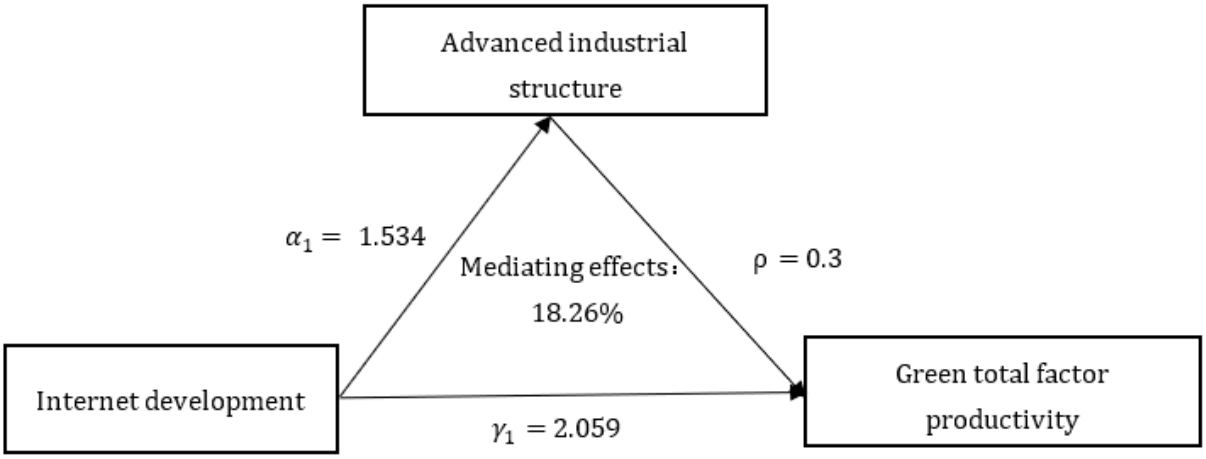

Figure 2. The mediating effect of advanced industrial structure.

For human capital advanced (Hum), as shown in columns (5) and (6) in Table 6, the coefficient α_1 is significantly positive at the 1% level ($\alpha_1 = 2.582$, $t = 8.14$), and the coefficient γ_1 is also significant ($\gamma_1 = 2.611$, $t = 5.99$). But the coefficient of the mediating variable ρ is not significant. Therefore, the stepwise regression method cannot determine the mediating effect of advanced human capital. According to the test steps of the mediating effect, the bootstrap mediating effect test was used to test whether $\rho\alpha_1$ was significantly equal to 0. As shown in row 3 of Table 7, the 95% confidence interval is [−0.7029, −0.0794], which does not contain 0. So this indicates that the mediating effect is significant. The direct effect and indirect effects of advanced human capital is 1.652 and −0.320, respectively and are significant at the 5% level. Since the indirect effect is opposite in sign to the direct effect, this indicates that advanced human capital presents a "masking effect". And as shown in Figure 3, advanced human capital plays a masking effect as a proportion of 19.37%. Da et al. found that the digital economy can promote the optimization of human capital structure and thus promote the enhancement of GTFP [38]. On this basis, this paper finds that the advanced human capital structure plays a masking effect in terms of the impact of internet development on GTFP. The finding means the contribution of internet development to GTFP is diminished when human capital advanced is not considered. And the contribution of the internet to GTFP is enhanced instead when advanced human capital is included. This may be because the development of the Internet will make society more in need of highly skilled human resources in the context of the digital economy. At the same time, many knowledge- and skill-intensive jobs require human resources with digital literacy, skills used in information networks and communication technologies, etc. Brown and Campbell argue from the perspective of workers returning to education that technology shocks will increase wage inequality in returns to education. The increase in the level of complementary skills and capital will lead to a rise in the need for advanced human capital, which will eventually promote advanced human capital and increase the proportion of high-quality and highly educated personnel. On the other hand, in the short term, the supply of highly skilled personnel has not kept pace with the growth in demand. This will lead to a rise in the wage level of skilled personnel and a rise in production costs for enterprises, putting negative pressure on economic development [58].

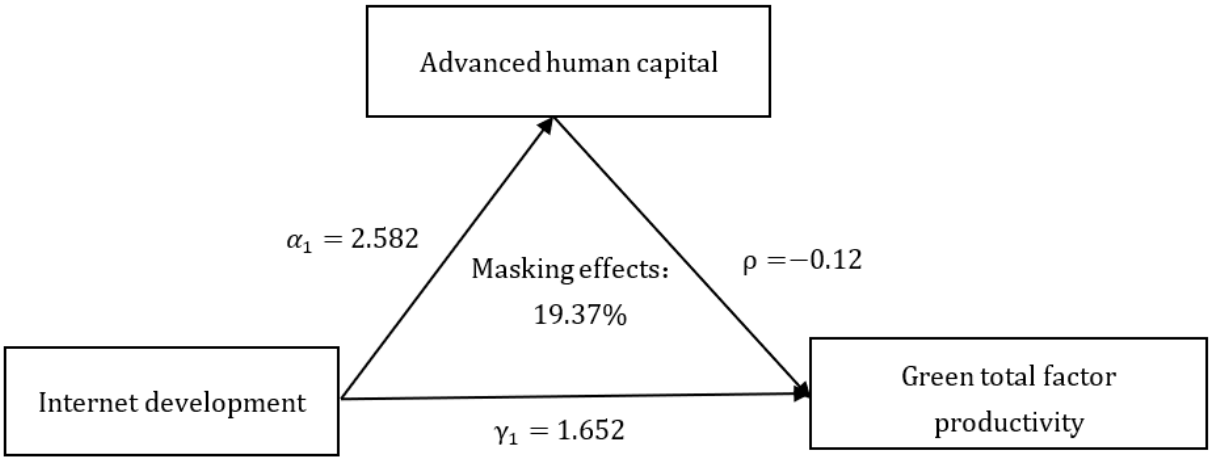

Figure 3. The mediating effect of advanced human capital.

For technological innovation (INN), as shown in columns (7) and (8) in Table 6, the coefficient α_1 is significantly positive at the 1% level ($\alpha_1 = 8.721$, $t = 8.45$). The coefficients of the mediating variables ρ and γ_1 are also significant ($\rho = 0.106$, $t = 4.67$; $\gamma_1 = 1.597$, $t = 3.97$), and the indirect effect $\rho\alpha_1$ sign is the same as the direct effect γ_1 with the same sign. Combined with the results of the bootstrap mediating effect test in Table 7, it can be concluded that technological innovation has a partial mediating effect in terms of the impact of internet development on GTFP. The partial mediating effects of technological innovation are shown in Figure 4, with a mediating effect of 36.60%. Liu et al. found that internet development can enhance green innovation capacity [8]. And on this basis, this paper finds that internet development can promote GTFP enhancement by promoting technological innovation. This may be due to the fact that the development of the Internet can reduce the cost of communication and, thus, enhance interregional cooperation and improve the efficiency of communication. In addition, technology provides a lower-cost competitive advantage for data-based innovation activities. Then, firms are able to analyze information regarding consumer groups based on big data and target innovation, thus reducing the innovation cost [59]. Hypothesis H2is partially verified.

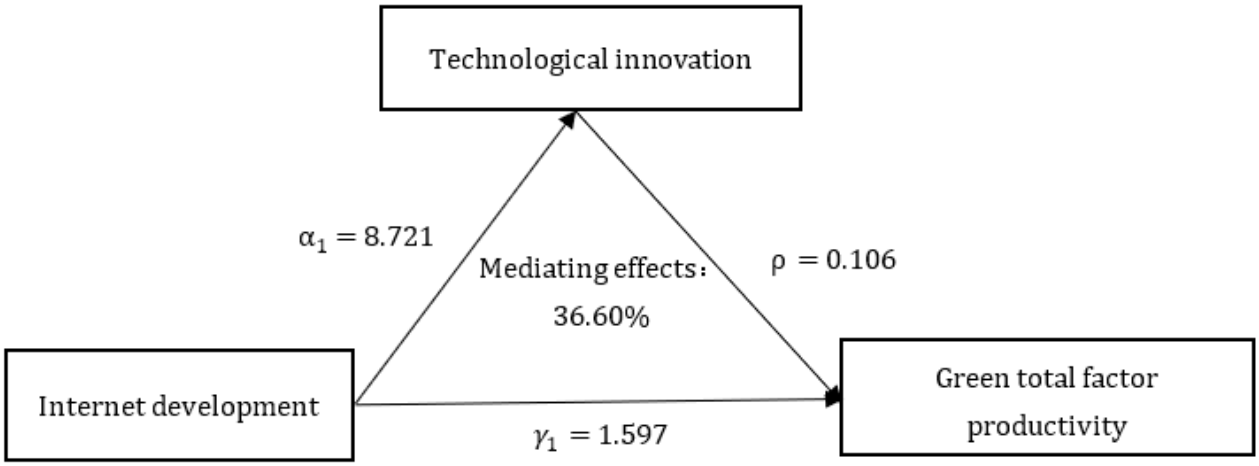

Figure 4. The mediating effect of technological innovation.

5.2. Threshold Effect Analysis

Next, to further test H3, the nonlinear impact effect of internet development on GTFP, this paper used a threshold effect model. First, this paper tested the existence and quantity of the threshold effect. The threshold value of the internet development threshold, the threshold value of advanced industrial organization and the threshold value of advanced

human capital were estimated using repeated bootstrap sampling 300 times. The estimation results are reported in Table 8.

Table 8. Threshold effect test.

	Threshold Type	Threshold Value	f-Value	*p*-Value	95% Confidence Interval
Hum	Single threshold	19.9594	223.01	0.00	[19.8097, 20.1813]
TC	Single threshold	2.5476	238.51	0.00	[2.4657, 2.7876]
INTER	Single threshold	0.5004	180.51	0.00	[0.4118, 0.5460]

The test results show that there was a single threshold effect of advanced industrial structure at the 1% significance level with a threshold value of 19.9594; that there was a single threshold effect of advanced human capital at the 1% significance level with a threshold value of 2.5476; and that there was also a single threshold effect of internet development at the 1% significance level, with a threshold value of 0.5004.

Table 9 shows the estimation results based on the threshold model. The results in column (1) show that when the human capital advanced index is less than the threshold, the promotion effect of internet development on GTFP is significant at the 5% level, with a coefficient of 0.534. When the human capital advanced index exceeds the threshold, the coefficient of internet development increases to 2.749, which is significant at the 1% level. It can be seen that, when the human capital structure index is higher than the threshold, the promotion effect of internet development on GTFP is more obvious. This may be because the more advanced human capital structure and the more highly skilled talents can more fully utilize internet information technology and promote GTFP. The regression results in column (2) of Table 9 show that when the index of advanced industrial structure is lower than the threshold value, the impact of the coefficient of internet development on GTFP enhancement is 0.517, which is significant at the 5% level. When the index of advanced industrial structure is higher than the threshold value, the impact coefficient of internet development on GTFP enhancement is 2.566, which is significant at the 1% level. It can be concluded that the degree of industrial structure upgrading can enhance the promotion effect of internet development on GTFP. The regression results in column (3) show that the coefficient of the impact of internet development on GTFP is 0.646 when the internet development index is below the threshold value of 0.5004, which is significant at the 5% level. When this threshold is exceeded, the coefficient value increases to 2.015, which is significant at the 1% level. This indicates that there is a nonlinear effect of internet development on GTFP enhancement, i.e., there is a "marginal increasing effect" of internet development on GTFP promotion. Guo et al., in 2016, found that internet development has a double threshold effect on the improvement of total factor productivity. The former is the threshold performance of the impact of the new technology on China's economy, with a weakened facilitating effect, while the latter is the threshold of the Internet net effect, with an enhanced facilitating effect [28]. Compared with the results of this paper, it can be concluded that the degree of internet development in China is now much higher than when internet technology was first introduced.

As can be seen from the results of the descriptive statistics in the previous section, the level of advanced industrial structure, the level of advanced human capital and the level of internet development in most provinces have not yet reached the threshold level. Therefore, promoting the upgrading of industrial structure, strengthening the cultivation of technical talents and increasing the internet penetration rate in these areas are of great significance to the high-quality development of the economy. Hypothesis 3 is proved.

Table 9. Threshold regression results.

Variables	(1) *GTFP*	(2) *GTFP*	(3) *GTFP*
INTER (*Hum* $\leq$ 19.9594)	0.534 **		
	(2.34)		
INTER (*Hum* > 19.9594)	2.749 ***		
	(13.73)		
INTER (*TC* $\leq$ 2.5476)		0.517 **	
		(2.70)	
INTER (*TC* > 2.5476)		2.566 ***	
		(7.22)	
INTER (*INTER* $\leq$ 0.5004)			0.646 **
			(2.30)
INTER (*INTER* > 0.5004)			2.015 ***
			(6.27)
Constant	−1.545	−1.076	−0.805
	(−0.90)	(−0.59)	(−0.42)
Controls	Yes	Yes	Yes
Observations	300	300	300
R-squared	0.719	0.726	0.745
Province	Yes	Yes	Yes
Year	Yes	Yes	Yes

** and *** indicate significant at the 5% and 1% levels, respectively.

6. Conclusions and Policy Recommendations

6.1. Conclusions

In the era of the digital economy, the Internet provides important support and is a major driving force for sustainable development. This paper empirically investigated the impact of internet development on green total factor productivity using panel data from 30 provinces in China and further studied the impact mechanism and nonlinear impact effects. The results show that, firstly, internet development significantly improves green total factor productivity, i.e., internet development significantly contributes to green total factor productivity. Secondly, in terms of the influence mechanism, internet development indirectly promotes green total factor productivity through industrial structure advancement, human capital advancement and technological innovation. Specifically, industrial structure advancement and technological innovation has a partial mediating effect, and human capital advancement produces the masking effect. Thirdly, from the results of the threshold analysis, there is a single threshold effect of advanced industrial structure, advanced human capital and internet development. The more advanced the industrial and human capital structure become, the stronger the contribution of internet development to green total factor productivity will be. And the higher the level of internet development is, the stronger the driving effect of internet development on green total factor productivity will be.

6.2. Policy Recommendations

Based on the above findings, this paper makes the following recommendations:

First, the government should vigorously optimize and improve the construction of internet infrastructure. The results of this paper show that there is a single threshold for the promotion of the internet for green total factor productivity characterized by an increasing marginal effect. At present, the level of internet development in most provinces in China has not reached the threshold value, which indicates that the dividends brought by internet development have not been fully released in most areas. Therefore, the state should vigorously strengthen investment in internet development construction in regions lagging behind in internet development and consciously tilt resources to regions with lower levels of internet development. At the same time, the government should play a guiding

role in the development of the internet industry and guide social capital into key areas of internet development.

Second, each local government should focus on guiding and encouraging green technological innovation. This paper finds that the mediating role of technological innovation is strong, accounting for 36.60%, but that the role of technological innovation for green total factor productivity is weak. Therefore, in order to expand the role of technological innovation in promoting green total factor productivity, government decision makers need to greatly encourage green technological innovation that is relevant to green development. Local governments need to support enterprises and schools in cultivating green technology innovation capabilities. At the same time, they should strengthen the control of pollutant emissions from enterprises. In addition, the government should make full use of fiscal and tax policies to encourage and support enterprises to utilize internet information technology for green product research and development. And certain concessions should be given in terms of R&D funds and talents.

Third, the state should continue to promote an advanced industrial structure at all levels. The research in this paper shows that an advanced industrial structure is an important transmission mechanism for internet enhancement of green total factor productivity. Therefore, the government should vigorously promote the integration of the Internet with traditional industries to facilitate the transformation and upgrading of traditional industries that are highly energy-consuming, polluting, and inefficient. These measures can expand the promotion effect of advanced industrial organization on green total factor productivity. In addition, when the advanced level of industrial structure reaches the threshold value, the role of internet development for green total factor productivity increases. Therefore, each regional province should formulate strong *or* weak industrial structural optimization policies according to the level of regional level of advanced industrial structure.

Finally, the government should strengthen the cultivation of high-tech talents. This paper's research finds that with an increase in the advanced degree of human capital structure, the role of the Internet in the enhancement of green total factor productivity also increases. Therefore, the state should strengthen the construction of the digital talent team and implement a "Talent Strengthening Strategy". Each local government should strongly invest in the development of higher education and encourage universities to build modern industrial colleges that focus on digitization. This will promote advanced human capital and realize the coordinated development of the Internet and talent.

6.3. Research Limitations

This paper initially investigated the role and impact mechanism of internet development on green total factor productivity and drew meaningful conclusions. However, there are still some shortcomings in this paper that could inspire further research. First, because of limited data, this paper used interprovincial panel data and did not involve microlevels. Further studies can use microlevel data, such as firm-level data, potentially leading to the model estimates being more accurate. Secondly, although the measure of internet development in this paper has advantages over previous single indicators, the indicator system needs to be further improved. Further research can refer to the need to produce more literature to add relevant indicators such as internet development environment and internet information resources. Finally, this paper did not involve research on the impact of internet development on green total factor productivity in different regions, i.e., heterogeneity study. Because of the large number of differences in the level of internet development among regions in China, heterogeneity studies play an important role in giving full play to the Internet for high-quality economic growth in different regions. Further research could divide China into eastern, central, western, and northeastern regions in order to further study the impact of the Internet on green total factor productivity separately.

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Abbreviations

The following abbreviations were used in this article:

GTFP	Green total factor productivity
INTER	Internet development
TC	Industrial structure upgrading
TS	Industrial structure rationalization
Hum	Advanced human capital
INN	Technological innovation
lnUR	Urbanization
Gov	Government intervention
FDI	Foreign investment
GDP	Economic development
Fin	Financial sector development

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