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Does the Digital Economy Promote Industrial Structural Upgrading?—A Test of Mediating Effects Based on Heterogeneous Technological Innovation

Jinqi Su ^{1,*}, Ke Su ¹ and Shubin Wang ^{1,2,*}

¹ School of Economics and Management, Xi'an University of Posts and Telecommunications, Xi'an 710061, China; sukeke0525@163.com

² Research Center of Chinese Management, Xi'an Jiaotong University, Xi'an 710049, China

* Correspondence: sujinqi@xupt.edu.cn (J.S.); wangshubin@xupt.edu.cn (S.W.)

Abstract: This paper proves that the development of the digital economy has become a new vector to promote the upgrading of China's industrial structure. In addition, heterogeneous technological innovation plays an intermediary role in the promotion of the industrial structure by the digital economy. This study aims to solve the following: whether the development level of the digital economy is positively promoting the upgrading of the industrial structure; whether technological innovation can promote the upgrading of the industrial structure; the path of the digital economy through which to promote the upgrading of the industrial structure and the heterogeneity of this path. The purpose of this study was to verify the digital economy and scientific and technological innovation to promote the upgrading of the industrial structure and the reality of the realization path; and to solve the problem of insufficient power for upgrading China's regional industrial structure against the background of the impact of the new generation of information technology. This study mainly adopted comprehensive evaluation and multivariate statistical analysis methods. The statistical basis for the study was data from 30 Chinese provinces from 2013 to 2018. The results confirm the hypothesis that the development of the digital economy and scientific and technological innovation have a positive role in promoting the upgrading of the industrial structure, and also prove that the intermediary role of heterogeneous technological innovation is crucial in the process of the digital economy promoting industrial upgrading. This conclusion can further give play to the role of the digital economy in promoting industrial structure upgrading, build a clean and intelligent industrial chain, solve the root cause of the lack of new drivers for China's industrial upgrading, and help to form a new development pattern of domestic and international double circulation, so as to achieve the high-quality and sustainable development of China's economy.



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Keywords: digital economy; industrial structure upgrading; technological innovation; mediating effect

1. Introduction

The leapfrog development of China's economy is obvious to all, but the long-term extensive industrial structure has brought severe environmental pressure. The transformation and upgrading of the industrial structure are a key part for realizing the transformation of the economy to high-quality development. Especially in the postepidemic era and the accelerated reshaping of China's industrial chain, the upgrading of the industrial structure is imperative. In the context of high-quality development, it is urgent to propose a new path to achieve environmentally friendly development while promoting industrial structure upgrading through the digital economy. As a strategic path to achieve high-quality development goals, technological innovation can promote the formation of a sustainable industrial structure in line with the new development concept in China [1]. In recent years, the development of the circular economy and the digital economy triggered by the fourth industrial revolution has brought about unprecedented risks and opportunities for

the stakeholders involved [2]. Among them, the development momentum of the digital economy is rapid. The continuous expansion of its connotation and its in-depth integration with various industries in the economy and in society have driven a series of digital transformations, continuously injecting new technologies, new models and new business genes into the process of transforming the industrial structure, in order to promote an economic model driven by innovation. The digital economy and technological innovation can optimize industrial structure by accelerating the development of green, clean and smart industrial chains [3]. During the fourteenth Five-year Plan, China has proposed that the key path to achieve high-quality economic development and form a new development pattern is to further promote the digital economy and build a digital China. At the same time, China will give full play to the driving role of high-tech industries, promote innovative, coordinated, green, open and inclusive development in various regions.

Does the digital economy promote the upgrade of the industrial structure? What is the implementation path? To answer these two questions, we need to take China's reality into account. The huge impact of the digital economy on human society is not comparable to that of the past, but relevant research into an accurate evaluation of its impact on the upgrading of the industrial structure is extremely scarce. Existing studies mainly focus on the internal mechanism of big data [4]; how information and communication technology promotes high-quality economic development [5,6]; and how the new economy promotes the upgrading of the industrial structure [7,8], creates employment opportunities [9], and promotes the transformation of manufacturing industry [10]. Zhang proposed that the digital economy should focus on both supply and demand, open up new space for industrial development, catalyze new fields of industrial development, and drive the industrial structure towards the medium-high end [7]. At present, most studies are theoretical explorations of the influence of the digital economy on a certain aspect, and the mechanism of the digital economy's influence on industrial upgrading needs to be further explored.

Research on the impact of the technological innovation on industrial transformation and upgrading mainly focuses on two aspects. On the one hand, it studies the mechanism of technological innovation on the internal advancement of various industries. Fu Hong, Mao Yunshi and others have proved through empirical analysis that there is an inherent dynamic mechanism in the process of industrial structure upgrading, and innovation has a positive role in promoting the process of industrial structure upgrading [11]. There are four main ways to realize technological innovation in China: technology introduction, imitative innovation, cooperative innovation, and independent innovation [12,13]. In the process of industrial structure upgrading, the carrying capacity and absorption capacity of various industries for technological innovation investment is a key factor related to whether the industrial technology level is fundamentally improved. On the other hand, it explores the impact of technological innovation on the transformation and upgrading of industries, and focuses on the process of technological innovation to promote the continuous upgrading of a proportion of the three major industries. Zheng Wei and Lu Yuanquan believe that improvement of the technological innovation level will promote the upgrading of the industrial structure in surrounding areas through spatial spillover effects [14]. Xu Kangning and others believe that the lack of technological innovation is one of the obstacles affecting China's industrial upgrading. Therefore, independent technological innovation is a key measure for China to surpass other countries' innovation capabilities [13]. China's independent innovation capability was established in the spillover of advanced foreign technology [13], and the economic structure is gradually evolving toward being service-oriented. There is an urgent need to remove the dilemma of technology introduction and imitative innovation that stifles innovation capability. Independent scientific and technological innovation should be developed to solve the key problem of core technology "stuck neck" and fundamentally promote the upgrading of the three major industries.

Existing research does not provide an accurate conclusion as to the main role of the digital economy in influencing industrial upgrading. The research results lack completeness and warrant further investigation. Zhao Tao and others believe that the digital economy

can increase entrepreneurial activity and achieve high-quality economic development [15]. Scientific and technological innovation is internationally recognized as the source of power for industrial upgrading. Based on the fact that technological innovation is an objective national strategy, this article will discuss from the perspective of technological innovation as the realization path of the digital economy affecting the upgrading of industrial structure. Although the literature on technological innovation and industrial structure upgrading has yielded many results, most of the research on their relationship with the digital economy is limited to theoretical research. Few scholars have placed the digital economy, technological innovation and industrial structure upgrading under the same framework for research, and there is a lack of in-depth exploration from the perspective of heterogeneity. As the digital economy is the source of power for economic growth and the core driving force for the conversion of old and new kinetic energy [7], studying the relationship between them has a direct and practical significance for the improvement of China's comprehensive national strength and the continuity and stability of high-quality economic development.

This paper attempts to use technological innovation as an intermediary to construct a complete indicator system for evaluating the development level of the digital economy. By establishing a panel regression model, the depth analysis of scientific and technological innovation, the digital economy and upgrading of the industrial structure of internal relations, and verifying scientific and technological innovation heterogeneity, we can clarify the intrinsic link between the three. It provides a theoretical basis and policy suggestions for realizing green and sustainable upgrading of the industrial structure. This paper mainly studies the following issues: (1) the impact of the digital economy on the upgrading of industrial structure; (2) the impact of the scientific and technological innovation on the upgrading of the industrial structure; and (3) the mediating effect of heterogeneous technological innovation. The theoretical model of this paper is shown in Figure 1.

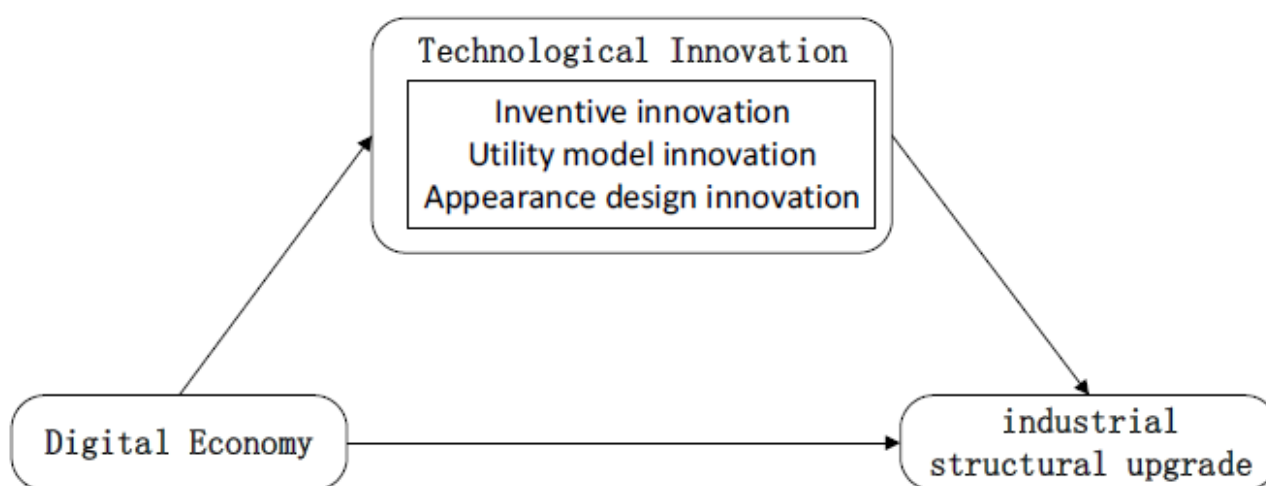


Figure 1. Theoretical model.

2. Background

2.1. Digital Economy

As a new driving force for economic development and transformation and upgrading, the digital economy has always been the focus of scholars' research. The term "digital economy" was first coined in the 1990s. In 1995, the OECD elaborated on the possible development trends of the digital economy. In 1996, Don Tapscott called the digital economy an era of networked intelligence, proposing that the digital economy is a network system built by human beings through technology, which links knowledge, skills and innovation to promote creative breakthroughs in wealth and social development [16]. Then, Nicholas Negroponte, in his book "Digital Existence", argued that the future would go from atoms to bits—computers and the Internet were bound to be ubiquitous—and that

the foresight of previous generations had already been validated [17]. In recent years, the OECD, the US Census Bureau, the G20, the UK and other countries and institutions have defined the digital economy to varying degrees. Although there is no consensus on the concept, the representative concept is the definition of the digital economy proposed by the G20, according to which, the digital economy is a series of economic activities that take digital knowledge and information as key production factors and use information and communication technology to promote economic structure optimization and improve efficiency. Zhang Peng made a new interpretation of the connotation of digital economy from the perspective of Marxist theory [18]. At present, all countries are actively exploring the development model of the digital economy, hoping to seize this new economic revolution of the digital economy and lead the trend of world economic development. The development of the digital economy has brought about new changes in the competitive pattern between countries and has become a new driving force for economic development [19]. The development of the digital economy not only helps to change the current problems of weak international competitiveness and lack of core competitiveness of the Chinese economy [20], but also helps to reduce poverty. Especially in terms of personal payments and small loans [21], at the same time, the digital economy also provides new ideas for and promotes the transformation of manufacturing industry [10]. In addition, the digital economy has also played a huge role in slowing down the downward pressure on traditional economic growth, promoting high-quality development, and promoting industrial upgrading and the development of the real economy [22,23]. The digital economy and the new generation of information technology play an important role in realizing the circular economy and forming the development pattern of domestic and international double circulation [24,25].

In addition, the current measurement of the digital economy by academic circles and government departments is generally divided into two categories: one is the direct method; that is, under the defined scope, the size of the digital economy in a certain region is calculated or estimated. The other is the comparison method, which compares the development of the digital economy in different regions based on multidimensional indicators to obtain the relative situation of the development of the digital economy or specific fields. Foreign institutions and countries that measure the digital economy mainly include the European Union, the US department of commerce, the organization for economic cooperation and development, the world economy BBS, and the UN's international telecommunication union. The study of the digital economy which started earliest is the OECD, which provides international economic measures advice and is one of the most authoritative international organizations. There is long-term tracking and forward-looking research on the digital economy. The OECD's definition of the digital economy is based on broad perspectives, including inclusive, accounting and preliminary measurement perspectives [26]. The ICT Development Index of the International Telecommunication Union of the United Nations has long-term research accumulation and expertise, and it has a strong experience value for the evaluation of China's digital economy in terms of industry positioning, index selection and reference value. China's domestic digital economy-related index measures mainly include the China Academy of Information Communication (DEDI), China Electronics Information Industry Development Research Institute, the Shanghai Academy of Social Sciences Global Digital Economy Competitiveness Index, the TENCENT "Internet +" digital economy index, and the CAIXIN China digital economy index (CDEI). Overall, the international and domestic index systems have their own strengths and characteristics.

2.2. Scientific and Technological Innovation and Industrial Structure Upgrading

The new economic growth theory investigates the factors of economic growth, emphasizes the role of human capital, technology and other factors, and holds that a country's economic growth mainly depends on knowledge accumulation, technological progress and the human capital level. The importance of technological innovation is gradually highlighted in high-quality economic development, which is the inevitable result of economic

and social development. Especially in today's society, only by relying on technological innovation and technological progress can we truly realize the sustainable development of the economic cycle. Among the existing studies, Romer constructed the endogenous growth model of technological progress and highlighted that the internal power of economic progress mainly comes from the knowledge cost based on scientific and technological innovation [27]. Research by Pradhan shows that financial development can promote technological innovation in eurozone countries [28]. Based on the practice of China's economic development, scholars have discussed scientific and technological innovation and the upgrading of the industrial structure from various perspectives and methods. Bai Junhong and others have proved that scientific and technological innovation has a significant positive impact on economic growth at both theoretical and empirical levels [29]. Ya Cheng, Usama Awan, Shabbir Ahmad and Zhixiong Tan believes that continuous innovation in energy-saving technologies can reduce carbon emissions in order to establish a sustainable form of industrial structure [1]. Yu Chunhui and Yu Binbin studied the impact of industrial structure upgrading on economic growth, and found that the impact of industrial structure upgrading on economic growth was not stable, and whether it could promote economic growth was related to many factors [30]. Several scholars, such as Cai Yuezhou and Fu Yifu, placed technological innovation, industrial structure and economic growth into the same framework for analysis, but they also studied their contributions to economic growth separately, and found that their contribution to economic growth varies with the changes in the economic environment [31]. Other scholars have studied the relationship between scientific and technological innovation and industrial structure, and found that they influence and promote each other. Technological progress triggered by technological innovation has affected the direction and speed of industrial development, which will, in turn, drive technological innovation through demand and synergistic effects. These studies show that scientific and technological innovation is closely related to the upgrading of industrial structure, and is an important part of establishing a green intelligent production system, realizing a green supply chain [3], and building a modern economic system.

2.3. Digital Economy and Industrial Structure Upgrading

The current literature on the impact of the digital economy on the industrial structure can be roughly divided into three types: the digital economy is promoting the transformation and upgrading of the industrial structure [32]; government intervention indirectly affects the upgrading of the industrial structure by influencing the development level of the digital economy [33]; a higher level of digital economy development in a region can promote the optimization and upgrading of industrial structure in the region and surrounding areas through significant agglomeration effect [34]. China's economy has entered a new normal driven by innovation. During the epidemic and in the postepidemic era, the application of digitization, intelligence, and technological innovation has played a significant role [35]. The digital economy with information technology at its core is bound to have a positive effect on high-quality economic development [15]. An important driving force for the recovery of productivity in the United States is the development and application of ICT [36]. Oliner and Dale W found that information and communication technology has a significant effect on the promotion of the US economy through calculations [37,38]. Abdul believes that information and communication technology has a significant effect on India's economic growth [39]. It can be seen that ICT can promote economic growth in both developed and developing countries. In addition, Han Baoguo and Li Shiqi found that software and information technology services play a significant role in promoting China's economic growth [40]. As an important aspect of the digital economy, Internet technology will not only lead to changes in production technology conditions and new changes in the form of the production function, thereby providing a new way to promote supply side structural reforms, and it has also accelerated China's economic transformation and development in the context of the new economy [41].

3. Theoretical Analysis and Research Hypothesis

3.1. The Impact of the Digital Economy on the Upgrading of Industrial Structure

Information technology and digital technology creatively make economic development not only limited to “demographic dividend”, “market dividend”, wage level, foreign investment and other factors, but also provide knowledge and data empowerment for economic development and industrial upgrading. The digital economy is rapidly penetrating various industries [42], giving rise to a large number of new products, new forms of business, new technologies and new business models, through which the industrial structure upgrading is promoted. This paper analyzes the internal mechanism of the digital economy’s influence on industrial structure upgrading at the macro-, meso- and microlevels.

- (1) From a macroperspective, the digital economy promotes industrial upgrading by improving efficiency

The digital economy can improve the production efficiency of the three industries. Information and communication technology is the core of the digital economy. O’Mahony and Vecchi believe that information and communication technology can significantly promote the output growth of various industries [43]. On the one hand, the application of digital technology in the production, sales, logistics and other aspects of enterprises can improve the efficiency of enterprises in each production link and enhance the production efficiency of service-oriented enterprises [44]. On the other hand, emerging industries provide more opportunities for employment and education, and it is more convenient for entrepreneurs to obtain innovative resources [15]. The educational level of residents, the employment rate of the whole society, and labor productivity are increased, which promotes the production efficiency of the industry.

The digital economy can improve innovation efficiency. Big data provide a new impetus for innovation efficiency. The production and innovation efficiency of logistics, computer and other industries that are closely connected with big data platforms is far higher than traditional manufacturing industry [4]. Most emerging technologies evolve and upgrade from existing technologies, so there are few disruptive innovative technologies in traditional industries, and it is difficult to form innovative products and emerging industries. However, the digital economy overcomes these shortcomings. Innovation under the condition of the digital economy shows the characteristics of high innovation frequency. Innovative technologies and products emerge one after another and quickly form emerging industries, greatly improving the innovation efficiency of enterprises and industries and promoting the transformation and upgrading of the industrial structure.

The digital economy can improve synergistic efficiency. On the one hand, relying on the digital platform, consumers can search for the required products and obtain high-quality services at the lowest cost, and producers can search for various elements required for the development of a large number of enterprises in the case of minimizing business costs. Enterprises can accurately obtain consumer demand to guide production, targeted to provide consumers with the required products and services, reduce the cost of production and sales promotion, effectively reduce the enterprise inventory, improve the efficiency of coordination between enterprises and consumers. On the other hand, the combination of production factors in the digital era is different from the traditional pattern of production factors, and the status of factors changes greatly. The re-integration of new elements to promote the efficiency of coordination and collaboration of various production elements from multiple dimensions, therefore, accelerates the transformation of the industrial structure.

- (2) From a mesoperspective, the digital economy promotes industrial upgrading by fostering new industries and promoting industrial integration

The digital economy has led to the formation of new industries. The continuous innovation and breakthroughs of digital technology give rise to a large number of emerging industries, and the continuous development of new industrial forms is the process of the continuous evolution of industries. Industries directly formed with artificial intelligence as the core are mainly related to new chips, basic software, intelligent hardware, etc. The

industry directly formed by big data specifically involves the collection, analysis, storage and analysis of numbers and is the core value-added service of big data. The industry with the fifth-generation mobile communication technology as the core is the infrastructure industry support for the digital transformation of enterprises and the formation of emerging industries.

The digital economy is accelerating the deep integration of industries. The high permeability and substitutability of the digital economy determine its fast integration with the three major industries. The internetization of sales and procurement channels in the manufacturing industry reduces information asymmetry and allows the manufacturing industry to upgrade towards the direction of service [10]. The integration of the digital economy and agriculture has changed the traditional labor mode, effectively reduced the production cost of agricultural products, and improved the production efficiency of land. The development of e-commerce and platform economy has diversified the sales channels of agricultural products, and the sales efficiency is far higher than that of the existing model. The integration of the digital economy and service industry will expand the scope of service objects, diversify service contents, and improve service efficiency and quality.

- (3) From a microperspective, the digital economy drives industrial upgrading by changing the internal management and operation model of enterprises

The digital economy has promoted the upgrading of corporate organization. On the one hand, enterprise decision making has shifted from top managers to consumers as the main body of the innovative decision-making model. On the other hand, in the digital age, “decentralization and de-hierarchy” have changed the relationship between employees and managers, which has gradually become flat from the vertical structure. Everyone acts as a manager to stimulate the innovation and entrepreneurship potential of every employee, so that they can fulfill said potential while creating the maximum benefits for the enterprise and realizing the innovation and upgrading of the enterprise, which then transforms and upgrades the industry.

The digital economy changes the business model of enterprises. Data are the most valuable 21st century “energy” and factors of production. The exponential growth of data can only be processed, cleaned, analyzed, processed, and integrated through digital technology to find the value contained in massive data, accurately target the potential needs of target users, transform existing production and business models, and use the “experience + product + service” operating model. With user experience as the guide, the production and sales processes of the enterprise should be adjusted at any time to modularize the production and operation links, urge enterprises to achieve innovation and upgrading while maximizing profits.

Based on the above analysis, the following hypotheses are now proposed:

Hypothesis 1. *The development of the digital economy can promote the upgrading of the industrial structure.*

3.2. The Impact of Heterogeneous Technological Innovation on the Upgrading of Industrial Structure

As an endogenous variable of economic growth, technological innovation drives industrial upgrading to achieve technological progress [11]. China’s industrial upgrading is the key to the formation of enterprise innovation ability [12], the government encourages small- and medium-sized enterprises to improve their own innovation level through mutual learning with high-tech enterprises, which will boost the upgrading of the regional industrial structure [45]. Anderson and Tushman proposed that scientific and technological innovation can be understood as a cyclic process of continuous technological breakthrough, which is the driving force for industry to achieve leapfrog upgrading [46].

According to the different innovation content, scientific and technological innovation ability can be regarded as the comprehensive reflection of three kinds of heterogeneous scientific and technological innovations: invention innovation (1) in Appendix A, utility

model innovation (2) in Appendix A, and appearance design innovation (3) in Appendix A. Porter and Kaplinsky proposed for the first time that the upgrading of the industrial structure is to efficiently manufacture higher-quality products, or to become more efficient business activities due to the increase in competitiveness [47,48]. Sang Yu believes that to improve the ability of enterprises to gradually transform into a capital or technology-intensive market with huge profits and frequent innovative technologies, this process can be understood as an industrial structure upgrade [49]. The target of inventive innovation is to produce better, environmentally friendly products and improve production efficiency with higher cleanliness; utility model innovations focus on improving the practicality of new products and ongoing creative possibilities on the basis of existing products; design innovation aims to improve the aesthetics, artistry and adaptability of the product. Liu et al. proposed that the pioneers of a new market must take advanced production technology as the basis in order to develop new products with superior performance [50]. Inventive innovation embodies the three processes of “nothing-there-excellent” (from nothing to something, from there to excellent). The innovative technology-oriented innovation process is improving the technology of the enterprise. This will give rise to innovative changes in the cost, performance, and value of a brand-new product or an existing product, and will create a brand-new industry and market. The company will take the lead in mastering its own core technology to enhance its market competitiveness and obtain huge profits that surpass other companies. Among them, utility model innovation provides brand-new possibilities for the types, functions, and combinations of new products and new technologies with a focus on practical applications. Appearance design innovation makes brand-new products and technologies more suitable for social aesthetics and meets consumers’ needs for product appearance. The first batch of consumers’ subjective evaluations of product appearance or product utility will trigger the desire to shop, stimulate the gradual upgrade of consumer demand, and force various industries and enterprises to carry out independent technological innovation. The virtuous circle will effectively connect the products and consumers at the center of the upstream and downstream economic links of the industrial value chain, promote the transformation and upgrading of all links of the industrial chain, and then realize the upgrading of the whole industrial chain.

Based on the above analysis, the following hypotheses are now proposed:

Hypothesis 2. *Scientific and technological innovation can promote the upgrading of the industrial structure.*

Hypothesis 2a. *Inventive innovation can promote the upgrading of the industrial structure.*

Hypothesis 2b. *Utility model innovation can promote the upgrading of the industrial structure.*

Hypothesis 2c. *Design innovation can promote the upgrading of the industrial structure.*

3.3. The Mechanism of Technological Innovation in the Impact of the Digital Economy on Industrial Upgrading

The digital economy can promote the formation of innovative resources by changing the subject of innovation, information acquisition methods, and enterprise development methods. It can also promote technological innovation and upgrading through technology spillovers [51], demonstration effects, feedback effects, and improving technological innovation efficiency. The digital economy affects scientific and technological innovation mainly in three aspects: first, the digital economy can effectively simplify the information acquisition process of diversified innovation subjects. The digital platform diversifies innovation entities, broadens the channels for each entity to acquire relevant knowledge and advanced technologies, and provides technical sources and knowledge foundations for the innovation and evolution of existing technologies. Second, the digital economy reshapes the demand side by providing personalized services [7]. Digital empowerment promotes

the transformation of enterprise development from product orientation to user experience to meet user needs and user experience as the driving force [10]. The digital economy diversifies the quality and variety of new products, and is the basis for technological innovation. Third, the digital economy has a feedback effect. The widespread use of digital technology will prompt R&D companies to continually update and upgrade their products, and at the same time will enhance the demonstration effect of high-tech companies, force companies and consumers to learn and use new technologies, and promote technological cyclical innovation. Han Xianfeng and others found that the improvement of regional informatization can effectively improve the efficiency of technological innovation [51]. The use of information and communication technology can reduce communication costs; improve production processes; and optimize and integrate traditional industrial chains, value chains and economic ecosystems [52], in order to become an important enabler of innovation [53].

Comprehensively considering how technological innovation affects the upgrading of the industrial structure, we can clarify the internal evolutionary mechanism of the digital economy influencing industrial structure upgrading through technological innovation: under digital conditions, new models have led to disruptive changes in the business management model of enterprises, and new technologies have spawned emerging industries and promoted the digital upgrade of traditional industries, effectively improving the input and output efficiency of the production link and optimizing the allocation of resources, and thereby promoting the transition of the industrial level. The digital economy mainly includes the ICT industry, new business forms and models based on ICT, traditional industries based on ICT support and application [7]. Therefore, the role of technological innovation in the process of upgrading the industrial structure is accompanied by the application of breakthrough technologies, circulation and diffusion, and the resetting of innovative technologies will inevitably lead to the advancement of the industrial structure. The intermediary driving effect of scientific and technological innovation is an important starting point for transforming the technologies, products, industries and models generated by the digital economy into industrial and enterprise transformation and upgrading of productivity, which is the core force of industrial upgrading. By influencing market scale, factor resource allocation, employment structure, etc., it opens up new markets for emerging industries, broadens the development channels of traditional industries, and promotes the development of industries toward a higher quality and a greener sustainable direction. Jorgenson and others believe that after 2000, productivity growth in the United States began to be driven by innovations in products and production processes in industries that use information technology the most [54].

Based on the above analysis, the following hypotheses are now proposed:

Hypothesis 3. *Technological innovation plays a mediating role in the process of digital economy development promoting industrial structure upgrading.*

4. Research Design

4.1. Data Sources

This study used data from 30 provinces in Mainland China from 2013 to 2018 as the research sample. Due to the lack of statistical data in some provinces and municipalities in some years, the data of Hong Kong, Macao, Taiwan, and Tibet of China were excluded. The original data are mainly derived from the “China Statistical Yearbook”, “China Labor Statistics Yearbook”, “China Environment Statistics Yearbook”, “China Population and Employment Statistics Yearbook”, “China High-tech Industry Statistical Yearbook”, China’s Internet Development Statistical Report and Regional Statistical Yearbooks, etc. In order to avoid the impact of inconsistencies in the dimensions of the original data on the regression results, the data of all variables were processed by logarithms; the indicators of missing data were complemented by regression and interpolation; when calculating the digital

economy development index, for indicator units that were US dollars, the average exchange rate of the year was used for conversion.

4.2. Variable Design

4.2.1. Explained Variables

(1) Upgrading of industrial structure

This paper studies the impact of the development of the digital economy on the transformation and upgrading of the industrial structure. By referring to the research of Tu Hongwang [55], Lan Qingxin and Chen Chaofan [56], the hierarchical coefficient of industrial structure upgrading was used as a measure of industrial structure upgrading, which was recorded as *STRU*. This can reflect the change in the industrial structure of the internal level and the overall upgrade of industrial structure and the level of evolution.

Constructor as shown in type (1):

$$STRU_{it} = \sum_{m=1}^3 Q_{itm} \times m = Q_{it1} \times 1 + Q_{it2} \times 2 + Q_{it3} \times 3, 1 \leq STRU_{it} \leq 3 \quad (1)$$

In the formula, $STRU_{it}$ represents the hierarchical coefficient of the industrial structure upgrade in the i -th area in year t ; Q_{itm} represents the proportion of the m -th industry's GDP in the i -th region in year t ; m represents the 1, 2, 3 industries; the value of *STRU* is [1,3]; the closer its value is to 3, the higher the level of the industrial structure.

4.2.2. Explanatory Variables

(1) Measurement of Technological Innovation Ability

This paper studies the impact of technological innovation on the upgrading of industrial structure from the perspective of output. The number of patent grants can objectively reflect the true situation of technological innovation. Therefore, referring to the relevant literature [57], this study used the number of patent grants as an indicator to measure technological innovation, which was recorded as *TECH*. The "China Statistical Yearbook" provides the indicators and innovation content of different patents, the heterogeneity of scientific and technological innovation by technology content and degree of innovation from highest to lowest, followed by three patents for inventions, utility model innovation, and appearance design innovation.

(2) Measurement of the Level of Development of the Digital Economy

This article is based on the definition of the digital economy by the Group of Twenty (G20), referring to the relevant research results of the OECD [58], Xiang Shujian and Wu Wenjun [26], China Academy of Information and Communications Technology (4) in Appendix A, and Wu Xiaoyi [59] on the evaluation index system of the digital economy, taking into account the availability and reliability of data and selecting indicators that are as closely related to the digital economy as possible, establishing a digital economy evaluation index system consisting of three levels and three categories of indicators from the perspective of input and output, as shown in Table 1. This study set up a multidimensional evaluation system composed of three primary indicators of digital input, digital environment and digital output. It measured the development level of the digital economy in 30 provinces across the country from 2013 to 2018, and calculated the digital economy index through the entropy method. The development index was recorded as *DE*.

Table 1. Evaluation index system of digital economy development.

First-Level Index	Second-Level Index	Third-Level Index	Third-Level Index Explanation
Digital investment	Digital innovation	Digital talent investment	<ul style="list-style-type: none">• Employment ratio of information service employees• R&D personnel input intensity
		Digital technology investment	<ul style="list-style-type: none">• Technology market turnover
		Capital investment	<ul style="list-style-type: none">• Intensity of R&D investment• Proportion of investment in tertiary industry
		Data input	<ul style="list-style-type: none">• The number of Internet broadband access users per 10,000 people• Number of Web pages held
	Digital infrastructure	Mobile foundation	<ul style="list-style-type: none">• Mobile phone exchange capacity• Mobile phone penetration rate
		Internet foundation	<ul style="list-style-type: none">• Internet broadband access port• Cable line length
Digital environment	Information and communication technology applications	Personal	<ul style="list-style-type: none">• Number of digital TV users• Per capita telecom consumption
		Enterprise	<ul style="list-style-type: none">• Number of websites per 100 enterprises• Proportion of enterprises with e-commerce transaction activities
		Digital transaction	<ul style="list-style-type: none">• E-commerce sales accounted for the proportion of regional GDP• Express quantity
	Digital assurance	Digital policy system guarantee	<ul style="list-style-type: none">• Computer holdings
		Digital security	<ul style="list-style-type: none">• Domain holdings• Website holdings
Digital output	Digital effect	Economic efficiency	<ul style="list-style-type: none">• Information service industry operating income as a percentage of GDP• Operating profit margin
		Social progress	<ul style="list-style-type: none">• Urbanization rate• Disposable income per capita
		Ecological Benefits	<ul style="list-style-type: none">• Urban sewage treatment rate• Harmless treatment rate of municipal solid waste

4.2.3. Control Variable

(1) Degree of government intervention

By making up for the deficiency of the market mechanism, government regulation alleviates the contradiction of a one-way flow of quality factors to the eastern region with good economic benefits [60,61]. It has an important impact on the adjustment and transformation and upgrading of the industrial structure [14,53,60,61]. This paper takes the

proportion of local fiscal expenditure in regional GDP as a proxy indicator of the degree of government regulation, which is recorded as GOV.

(2) Human capital

Under the background of economic structure serving, the education level of the population in a country or region directly affects the degree of scientific and technological innovation, and then determines the stage of industrial development. In this paper, the proportion of college degree or above education level in the total number of people employed in each region was used as the proxy index of human capital, which was recorded as HUM.

(3) Infrastructure construction

The traditional infrastructure investment partly shifts to the new type of infrastructure investment, and the new type of infrastructure investment will promote the transformation and upgrading of the industrial structure from both sides of the supply and demand [62]. In this paper, per capita urban road occupancy was used as a proxy index for infrastructure construction, which was recorded as INFRA.

The variables are summarized and explained in Table 2.

Table 2. Summary of variable descriptions.

Variable Category	Variable Code	Variable Name	Index Selection
Explained variable	STRU	Industrial structural upgrade	Industrial structure upgrade level coefficient
Explanatory variable	DE	Digital economy development level	Digital Economy Index
Explanatory variable (Mediation variable)	TECH	Technological innovation	Number of patents granted
	INV	Inventive innovation	Number of invention patents granted
	UTI	Utility model innovation	Number of utility model patents granted
	DEG	Degree of government intervention	Number of design patents granted
Control variable	GOV	Degree of government intervention	Local fiscal expenditure as a percentage of regional GDP
	HUM	Human capital	The proportion of college degree or above in the total number of employees in the region
	INFRA	Infrastructure	Per capita urban road occupation rate (square meters)

4.3. Model Setting

Based on the proposed hypothesis, in order to effectively test the positive impact and effect of the development level of the digital economy and the degree of technological innovation on the upgrading of the industrial structure, the following basic measurement model is proposed for the direct transmission mechanism:

$$LNSTRU_{i,t} = \alpha_0 + \alpha_1 LNDE_{i,t} + \alpha_2 LNGOV_{i,t} + \alpha_3 LNHUM_{i,t} + \alpha_4 LNINFRA_{i,t} + \varepsilon_{i,t} \quad (2)$$

$$LNSTRU_{i,t} = \alpha'_0 + \alpha'_1 LNTECH_{i,t} + \alpha'_2 LNGOV_{i,t} + \alpha'_3 LNHUM_{i,t} + \alpha'_4 LNINFRA_{i,t} + \varepsilon_{i,t} \quad (3)$$

Among them, i represents the region; t represents the time; $STRU$ represents the upgrading of the industrial structure; DE represents the level of digital economy development; $\varepsilon_{i,t}$ represents the random disturbance term.

This paper draws on the methods and steps of Baron and Kenny [63], Wen Zhonglin and Ye Baojuan [64] to study the mediation effect, and constructs the test model as follows:

$$LNTECH_{i,t}^z = \beta_0^z + \beta_1^z LNDE_{i,t} + \beta_2^z LNGOV_{i,t} + \beta_3^z LNHUM_{i,t} + \beta_4^z LNINFRA_{i,t} + \varepsilon_{i,t}^z \quad (4)$$

$$LNSTRU_{i,t}^z = \gamma_0^z + \gamma_1^z LNDE_{i,t} + \gamma_2^z LNTECH_{i,t}^z + \gamma_3^z LNGOV_{i,t} + \gamma_4^z LNHUM_{i,t} + \gamma_5^z LNINFRA_{i,t} + \varepsilon_{i,t}^z \quad (5)$$

In Equations (4) and (5), $TECH_{i,t}^z$ represents three different types of scientific and technological innovation activities.

The steps to test the mediation effect are as follows: the development level of the digital economy in Model (2) has a significant role in promoting industrial upgrading; the development level of the digital economy in Model (4) has a significant impact on the technological innovation of the intermediary variables; after the scientific and technological innovation capability is incorporated into the equation in Model (5), the regression coefficient of the development level of the digital economy on the upgrading of the industrial structure is significantly reduced, and so the scientific and technological innovation capability plays a full or partial intermediary role. At this time, it is divided into the following two situations: if the regression coefficient drops significantly but is not zero, the technological innovation capability is a partial mediating effect; if the regression coefficient is reduced to zero, the technological innovation capability is a complete mediating effect [30].

5. Empirical Analysis

5.1. Descriptive Statistical Analysis of Variables

Before the analysis of the sample data, the descriptive statistics of the research variables were first carried out, and the results are shown in Table 3. The mean value, standard deviation, maximum value and minimum value of industrial structure upgrading (STRU) are 2.375, 0.123, 2.194 and 2.806, respectively, indicating that there is a minimal difference in the overall level of the industrial structure. The average value of the digital economy development level (DE) is 0.217, the standard deviation is 0.177, the minimum value is 0.078, and the maximum value is 1, indicating that there is a large gap in the development level of the digital economy in different provinces. The average value of the technology innovation level (TECH) is 5.341, the minimum value is 0.051, the maximum value is 47.808, and the standard deviation is 7.379, which is larger than the average value, indicating that there is an imbalance and regional differences in the innovation level and an imbalance in the innovation level. Breakthrough innovations and digital technologies have a first-mover advantage in the regions where they are first deployed, so the late-mover regions are obviously underpowered and the development level of the digital economy and technological innovation is relatively weak.

Table 3. Variable descriptive statistics.

Variable	Average	Standard Deviation	Minimum	Max
STRU	2.375	0.123	2.194	2.806
DE	0.217	0.177	0.078	1.000
TECH	5.341	7.379	0.051	47.808
GOV	0.251	0.101	0.121	0.627
HUM	19.070	9.671	8.330	57.400
INFRA	15.790	4.595	4.110	25.820

Before regression analysis, in order to avoid the existence of multicollinearity in the data, the variance inflation factor (VIF) of each variable was tested and diagnosed. The results showed that the VIF values of most variables were less than 5, far less than the critical value of 10, indicating that there was no serious multicollinearity problem among the data. In order to select the panel model, the F-test was conducted to determine whether the mixed effect or the fixed effect was selected, and the test results showed that the null hypothesis was rejected at the significance level of 1%. Then, the Hausman test was conducted, and the test results showed that the χ^2 statistic was 19.360, and the P value was 0.003. Therefore, the fixed effects model was selected for empirical analysis.

5.2. Empirical Test of the Impact of Digital Economy Development and Technological Innovation on Industrial Structure Upgrading

In order to explore the impact of the digital economy and technological innovation on the upgrading of industrial structure, it is necessary to study the influence of indepen-

dent variables (digital economy) and mediating variables (technological innovation) on dependent variables (record the model that only contains control variables as model (1)), and then add independent variables and mediating variables (Hypotheses H1 and H2) to Model (1) in turn. Table 4 shows the regression results of the impact of the digital economy and technological innovation on the upgrading of the industrial structure.

Table 4. Regression results of the impact of the digital economy and technological innovation on the upgrading of the industrial structure.

	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)
Variable	STRU	STRU	STRU	STRU	STRU
DE		0.028 ** (0.011)		0.027 *** (0.005)	
TECH			0.048 *** (0.005)		0.029 *** (0.006)
GOV	0.079 *** (0.022)			0.084 *** (0.020)	0.049 ** (0.019)
HUM	0.084 *** (0.018)			0.079 *** (0.015)	0.054 *** (0.014)
INFRA	0.056 ** (0.024)			0.063 *** (0.017)	0.019 (0.016)
CONSTANT	0.587 *** (0.061)	0.912 *** (0.019)	0.378 *** (0.052)	0.639 *** (0.067)	0.433 *** (0.076)
R-squared	0.607	0.051	0.608	0.656	0.721
model	FE	FE	FE	FE	FE
r2_a	0.600	0.046	0.605	0.648	0.715
F	42.56	6.675	86.11	34.56	37.80

Note: (1) **, *** indicate significance at the statistical level of 5%, and 10%, respectively; (2) the robust standard errors are in parentheses.

It can be seen from Table 4 that in Model (1), the regression coefficients of government intervention (GOV) and human capital (HUM) were positive at the significance level of 1%, which was 0.079 and 0.084, respectively. The regression coefficient of the infrastructure construction (INFRA) was 0.056, which is positive at the significance level of 5%. The result of adding only the digital economy to the benchmark Model (1) is shown in Model (4). The variable digital economy (DE) is positive at the 1% significance level, and hypothesis H1 is verified. The result of adding only technological innovation to the benchmark Model (1) shows that in Model (5) the variable technological innovation (TECH) is positive at the 1% significance level, and hypothesis H2 is verified.

The above research results show that the higher the degree of local government control over the market, the greater the investment in human capital, and the higher the level of infrastructure construction, the larger the advancement in the level of industrial structure. The development of the digital economy and technological innovation capabilities can significantly promote the upgrading of the industrial structure.

5.3. Empirical Test of the Mediating Effect of Scientific and Technological Innovation

This study used a hierarchical regression model to test whether technological innovation has a mediating effect between the digital economy and industrial upgrading, as shown in Table 5. Model (9) took the upgrading of the industrial structure as the dependent variable, and Models (6) to (8) took technological innovation as the dependent variable. Among them, Model (6) only incorporated the control variables and served as the benchmark model.

Table 5. Test results of mediation effect.

	Model (6)	Model (7)	Model (8)	Model (9)
Variable	TECH	TECH	TECH	STRU
DE		0.508 ** (0.214)	0.529 *** (0.132)	0.014 *** (0.004)
TECH				0.026 *** (0.005)
GOV	1.064 *** (0.346)		1.149 *** (0.284)	0.055 *** (0.018)
HUM	1.029 ** (0.376)		0.917 *** (0.294)	0.055 *** (0.014)
INFRA	1.251 ** (0.544)		1.386 *** (0.388)	0.027* (0.015)
CONSTANT	5.309 *** (1.085)	10.972 *** (0.370)	6.303 *** (0.856)	0.477 *** (0.080)
R-squared	0.488	0.066	0.557	0.732
model	FE	FE	FE	FE
r2_a	0.479	0.061	0.547	0.724
F	18.91	5.625	19.37	34.77

Note: (1) **, *** indicate significance at the statistical level of 5%, and 10%, respectively; (2) the robust standard errors are in parentheses.

It can be seen from Table 5 that in Model (8), the elasticity coefficient of the digital economy was 0.529, which surpassed the 1% significance test; compared with Model (4), the regression coefficient of the digital economy was reduced to 0.014 after the independent variables and the mediating variables were included in Model (9), which was significantly lower than the 0.027 in Model (4), and the regression coefficient of scientific and technological innovation was 0.026; all surpassed the 1% significance test.

Based on the above analysis, from the test steps of the mediation effect in the model setting of this paper, hypothesis H3 is verified. If the digital economy improves by 1 unit, the technological innovation can increase by 0.529 units; if the technological innovation improves by 1 unit, the industrial structure upgrading can increase by 0.026 units. Overall, for every unit that the digital economy improves, the industrial structure can be upgraded by 0.014 units through the technological innovation of intermediary variables; the ratio of the mediating effect to the total effect is 50.99%. It can be considered that 50.99% of the impact of the digital economy on the upgrading of the industrial structure is achieved through technological innovation.

From the above research, it can be seen that while the rapid development of the digital economy significantly promotes technological innovation, technological innovation plays an intermediary role between the digital economy and industrial upgrading, and is also a key element for the digital economy to enhance the level of regional industrial structure.

5.4. Further Empirical Testing of the Mediating Effect of Heterogeneous Technological Innovation

In order to further explore the difference in the mediating role played by heterogeneous technological innovation between the digital economy and industrial upgrading, three different technological innovation activities are introduced into Equations (4) and (5). The test results are shown in Table 6. Models (10)–(12) are the regression results of the digital economy's impact on heterogeneous technological innovation, and Models (13)–(15) are the regression results of the impact of heterogeneous technological innovation on industrial structure upgrading.

Table 6. Regression results of the mediating role of heterogeneous technological innovation.

	Model (10)	Model (11)	Model (12)	Model (13)	Model (14)	Model (15)
Variable	INV	UTI	DEG	STRU	STRU	STRU
DE	0.385 *** (0.081)	0.586 *** (0.149)	0.343 ** (0.156)	0.018 *** (0.005)	0.015 *** (0.004)	0.022 *** (0.004)
INV				0.026 *** (0.006)		
UTI					0.021 *** (0.005)	
DEG						0.016 *** (0.004)
GOV	1.027 *** (0.317)	0.727 ** (0.295)	2.224 *** (0.468)	0.058 ** (0.022)	0.069 *** (0.018)	0.049 ** (0.019)
HUM	1.844 *** (0.228)	1.025 *** (0.314)	0.013 (0.386)	0.031 * (0.016)	0.058 *** (0.015)	0.078 *** (0.016)
INFRA	1.072 *** (0.299)	1.654 *** (0.452)	0.799 * (0.393)	0.035 ** (0.016)	0.029 * (0.016)	0.050 *** (0.014)
COSTANT	2.218 ** (1.055)	4.273 *** (1.012)	10.023 *** (1.308)	0.582 *** (0.075)	0.552 *** (0.072)	0.482 *** (0.074)
R-squared	0.697	0.530	0.277	0.724	0.716	0.709
model	FE	FE	FE	FE	FE	FE
r2_a	0.690	0.519	0.261	0.716	0.708	0.701
F	46.22	17.48	7.546	28.55	33.75	31.57

Note: (1) *, **, *** indicate significance at the statistical level of 1%, 5%, and 10%, respectively; (2) the robust standard errors are in parentheses.

It can be seen from Table 6 that in Models (13)–(15), the regression coefficients of heterogeneous technological innovation affecting industrial structure upgrading were all positive at the 1% significance level, and the regression coefficients were 0.026, 0.021, and 0.016. The above results clearly show that technological innovation affects industrial upgrading in terms of the technological content and degree of innovation. The higher the technological content and degree of innovation, the stronger the upgrading of the industrial structure toward mid-to-high end. Therefore, hypotheses H2a, H2b, and H2c have been verified.

In Models (10)–(12), the influence of the digital economy on invention innovation (INV), utility model innovation (UTI) and design innovation (DEG) was different, but all the effects were significant, indicating that the development of the digital economy is helpful for the improvement of the heterogeneous technological innovation level. The ascending intensity is in the order of appearance design innovation < invention innovation < utility model innovation. In Models (13) to (15), the regression coefficients of the digital economy were all positive at the significance level of 1%, which were 0.018, 0.015 and 0.022, respectively, significantly lower than the 0.027 regression coefficient of digital economy in Model (4). Based on the above analysis, it can be seen from the test steps of the model-setting part of the mediation effect in Section 4 of this article that the mediation effect of heterogeneous technological innovation is significant, and the ratio of the mediation effect to the total effect is 36%, 44%, and 20%, respectively. The results show that the intensity of the intermediary role played by technological innovation in the process of the digital economy promoting industrial upgrading is ranked in descending order: utility model innovation, invention innovation, and appearance design innovation.

This study suggests that the reasons that the utility model innovation and innovation invention have dominant mediating effects are as follows: first, driven by digital technology, the reason for the leap from a low-end to mid-to-high-end industrial structure is

that the economic structure tends to be service-oriented, and then the service industry integrates practical technology and advanced technology to develop in the direction of high technology and intelligence. China's economic structure is continually being adjusted and upgraded. New technologies have brought about platform-based and widespread use to change the consumer consumption structure, while also driving related industries and giving rise to new industries, and the industrial structure has subsequently advanced. Second, social progress and the continual increase in people's income levels have led to changes in the main contradictions in Chinese society. Consumers are pursuing the individual needs of innovative products and the uniqueness of appearance designs. Enterprises are eager for new technologies to accelerate the transformation into productivity. This has prompted social participants to have a steep rise in the practicality, usability, and integration of emerging technologies. In a few years, China's economic model has undergone unprecedented changes, forcing industries and enterprises to continually carry out internal innovative technology research and development and external technology exchanges in the process of intelligent transformation; promote the conversion of scientific and technological innovation achievements; and transform traditional production, operation, sales and logistics models. The "Internet of Everything" is developing in a broader, faster, and deeper direction, prompting a shift in the industrial structure toward a higher level. Third, the process innovation contained in the invention and innovation has promoted changes in the production mode of enterprises, provided more convenient production processes, reduced production costs, and improved production efficiency. The new products can achieve sufficient mass production to meet the market demand, strengthen the industrial competitiveness, form economies of scale and scope, and improve the industrial structure.

5.5. Robustness Test

5.5.1. Robustness Test of the Impact of Digital Economy and Technological Innovation on Industrial Structure Upgrading

In order to test the robustness of the conclusions of this study, the following tests were conducted from two aspects: replacement variables and endogeneity of variables. First, the robustness of the impact of the development of the digital economy on the upgrading of the industrial structure was further verified through variable substitution. At the same time, the gross product of the tertiary industry (STRU2) was used to replace the proxy variable of the industrial structure level coefficient (dependent variable), and the number of patent applications (TECH2) was used to replace the proxy variable of the degree of technological innovation (independent variable). The test results are shown in Table 7. Secondly, considering that the digital economy and the upgrading of the industrial structure may have endogenous problems caused by two-way causality, this paper adopted a one-period lag (L.DE) regression test for the variable digital economy. From Models (16) and (17), it can be seen that the regression results were not replaced by dependent variables and passed the robustness test of different variables. It can be seen from Models (18)–(20) that the regression results were the same as the previous research results of this article, which shows that the research conclusions of this article are robust.

5.5.2. Robustness Test of the Mediating Effect of Heterogeneous Technological Innovation

In order to verify the robustness of the mediating role of technological innovation and heterogeneous technological innovation in the process of digital economy promoting industrial upgrading, this paper used the Sobel test and bootstrap test as robustness tests. The results are shown in Table 8. It can be seen from Table 8 that when technological innovation was used as a mediating variable, the Sobel statistic value was 4.136, which is greater than the critical value of 0.970 at the 5% significance level, and the Bootstrap confidence interval did not include 0. The above analysis shows that the results of the mediation effect through the stepwise regression test are robust. When heterogeneous technological innovation was used as an intermediary variable, the Sobel test results were the same as the bootstrap confidence interval test results. This shows that the mediation effect is significant, and

there is no significant difference between the results of the mediation effect robustness test and the previous research conclusions.

Table 7. Robustness test regression results.

	Model (16)	Model (17)	Model (18)	Model (19)	Model (20)
Variable	STRU2	STRU2	STRU	STRU	STRU
DE	0.290 *** (0.045)				
L.DE			0.021 *** (0.007)	0.028 *** (0.004)	0.016 *** (0.003)
TECH					0.027 *** (0.005)
TECH2		0.377 *** (0.082)			
GOV	0.302 (0.191)	0.242 (0.234)		0.092 *** (0.017)	0.060 *** (0.015)
HUM	0.925 *** (0.141)	0.779 *** (0.145)		0.070 *** (0.014)	0.033 ** (0.013)
INFRA	0.854 *** (0.192)	0.364 (0.244)		0.053 *** 0.707 ***	0.026 * (0.013)
CONSTANT	5.065 *** (0.642)	2.752 *** (3.406)		(0.064) (10.96)	0.545 *** (0.068)
R-squared	0.631	0.692	0.044	0.584	0.705
model	FE	FE	FE	FE	FE
r2_a	0.623	0.685	0.0374	0.572	0.695
F	50.32	53.44	8.634	33.35	43.02

Note: (1) *, **, *** indicate significance at the statistical level of 1%, 5%, and 10%, respectively; (2) the robust standard errors are in parentheses.

Table 8. Mediation effect test results based on Sobel test and bootstrap test.

Mediating Variable	Sobel Test	Bootstrap (95% Confidence Interval)	
		Lower Limit	Upper Limit
TECH	4.136 ***	0.0138	0.0381
INV	3.985 ***	0.0178	0.0356
UTI	2.649 ***	0.0136	0.0443
DEG	5.090 ***	0.0202	0.0494

Note: *** indicate significance at the statistical level of 10%, respectively.

6. Conclusions

6.1. Discussion

With the in-depth development of the digital economy, this article focuses on the relationship between the digital economy and the upgrading of the industrial structure, and explores the way in which the digital economy affects the upgrading of the industrial structure. The research results explain the relationship between the digital economy and the upgrading of the industrial structure, and provide practical suggestions for the upgrading of China's regional industrial structure and high-quality sustainable economic development. This paper constructed an evaluation index system for the digital economy from the three aspects of input, output and environment. Based on the analysis of the mechanism of the digital economy's impact on the upgrading of the industrial structure, it used the provincial panel data from 2013 to 2018. From the perspective of heterogeneity, the impact of China's digital economy development on the upgrading of the industrial structure and its internal mechanism, as well as the intermediary mechanism of technological

innovation in the relationship between the two, was empirically examined. The empirical results show the following:

1. The digital economy has a positive impact on the transformation and upgrading of the regional industrial structure. The digital economy that includes new production factors produces new industries by itself, and new business formats formed by the in-depth integration of a new generation of information technology and various industries. The internal production and business model of the enterprise have changed. The deeper and more extensive the application of the digital economy, the faster and higher the process and quality of the industrial structure upgrading.
2. Technological innovation has a positive impact on the upgrading of regional industrial structure and has a heterogeneous effect. The degree of innovation and technological content play a decisive role in it. Therefore, invention and innovation have a significant role in promoting the upgrading of the industrial structure. Technological innovation can achieve the upgrading of the industrial structure by improving the material and technological basis of industrial production, promoting the division of labor, and changing the mode of resource allocation of production factors. Technological improvement, innovation, and breakthrough progress are all key steps to promote the upgrading of the industrial structure.
3. Technological innovation plays an intermediary role in the digital economy's upgrading of the industrial structure, and this mechanism is mainly realized through utility model innovation and invention innovation, but the intermediary role of design innovation should also not be ignored. All sectors of the economy and society should focus on the practicability, applicability and usability of advanced technologies in the context of digital technological changes, and improve and upgrade products, processes, and designs. In this way, the economic structure tends to be service-oriented, and the industrial structure is upgraded.

6.2. Contribution to Research

The contribution of this article is mainly manifested in two aspects: on the one hand, from the perspective of input and output, based on the development law and connotation of the digital economy, it establishes a digital economy indicator evaluation system. This has an important practical value for the measurement and development of the digital economy. On the other hand, the internal mechanism of the digital economy affecting the upgrading of the industrial structure is proposed. This article attempts to solve the problem from the three levels of "macro-medium-micro", the in-depth exploration of how the digital economy mainly promotes industrial transformation and upgrading, and a comprehensive analysis of the role of heterogeneous technological innovation in affecting the upgrading of the industrial structure. The role of heterogeneous technological innovation in the process of the digital economy influencing industrial structure upgrading should be further explored to broaden the depth and breadth of existing research.

6.3. Implications

This paper provides a theoretical basis and effective ways for local governments in China to play the leading role in the digital economy with the help of the innovation and development of science and technology, and puts forward effective suggestions for promoting industrial progress and realizing circular, green and sustainable economic development. Based on the research results of this article, the following suggestions are made:

1. This paper argues that in the process of industrial structure transformation and upgrading, the government should pay attention to the key position of the digital economy as a new driving force. On the one hand, the government should increase investment in digital and new infrastructure construction, vigorously develop digital industry and related industries, boost the digital transformation of traditional industries, and ensure the dominant position of information and communication

technology. On the other hand, we should make use of China's strong demographic dividend, rely on digital platforms, expand the market scale as the real carrier of industrial structure evolution, give full play to the advantages of economies of scale by relying on the huge domestic market, and release the consumer demand of residents. In this way, we will promote the construction of a new development pattern in which the domestic and international double cycles promote each other.

2. Stimulating scientific and technological innovation is an effective transmission path for the digital economy to affect the upgrading of the industrial structure, which indicates that the two-wheel drive formed by the digital economy and mass innovation can accelerate the transition of the industrial structure. First, local governments at all levels should take digitalization as the leading factor, implement the development strategy of innovation-driven industry optimization and upgrading, integrate all kinds of innovation factors, strengthen the leading role of scientific and technological innovation, open up the technological channel of industrial structure upgrading, and provide a solid foundation for realizing the stable and high-quality development of China's economy. Second, enterprises should pay attention to the development of the digital economy in the peripheral environment while focusing on innovation, and take digital technology and scientific and technological innovation as a fundamental basis on which to promote industrial transformation and upgrading.
3. To achieve a two-wheeled innovative drive mode where invention and innovation go hand in hand with practical innovation, on the one hand, we must enhance the ability of invention and innovation, strengthen the talent and scientific research funding support for advanced technology industries, encourage production departments to carry out independent innovation, overcome the problem that "stuck neck" technology is constrained by others as soon as possible, break technical barriers, and provide the technology for industrial upgrading. On the other hand, we must enhance the output level of scientific and technological innovation, increase the conversion rate for scientific and technological achievements, and encourage industrial departments and enterprises to increase multifaceted and in-depth co-operation with scientific research institutes and universities. It is essential to integrate the production system with technology, strengthen the application and promotion of innovative technologies, promote the formation of productivity as soon as possible from innovative results, and form a strong and long-term driving mechanism for industrial upgrading.

6.4. Research Gaps and Direction of Further Studies

Due to the limited space of this article, the following limitations still exist: first, this paper discusses the digital economy through heterogeneous scientific and technological innovation to promote the upgrading of the industrial structure, but ignores whether there are other ways to implement the upgrading of the industrial structure. Second, since there is no unified framework for the measurement of the digital economy at present, the index system constructed in this paper based on the relevant literature research to measure the development level of the digital economy may have a special influence on the research results. Finally, whether the research of this paper can be extended to the upgrading of the industrial structure in the international scope is yet to be elucidated. The above problems need to be solved in our follow-up research.

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Data Availability Statement: The availability of these data is limited. These data come from the official national statistical database of China, and can be obtained with prior permission on the websites of these publishers.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

- (1) Invention and innovation refer to new technical solutions proposed for products, methods or improvements. It is an internationally accepted core indicator that reflects the technology with independent intellectual property rights.
- (2) Utility model innovation refers to a new technical solution suitable for practical use proposed for the shape, structure or combination of the product, which reflects the situation of technological achievements with a certain technical content.
- (3) Appearance design innovation refers to a new design that is aesthetically pleasing and suitable for industrial applications based on the shape, pattern, color or combination of the product, which reflects the status of design achievements with independent intellectual property rights.
- (4) See “White Paper on China’s Digital Economy Development (2020)”. http://www.caict.ac.cn/kxyj/qwfb/bps/202007/t20200702_285535.htm, accessed on 5 September 2021.

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