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The Impact of Digital Economy on Innovation Efficiency of New Energy Enterprises: Evidence from the Perspective of Innovation Value Chain

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ABSTRACT

Based on the perspective of the innovation value chain, this paper divides the technological innovation of new energy enterprises into research and development and results transformation stages, uses the panel data of listed Chinese new energy enterprises from 2016 to 2021 to test the impact of urban digital economy development on the two-stage innovation efficiency, and examines the moderating role of organizational inertia and entrepreneurship on the relationship between the two. The study found that the development of the digital economy has significantly improved the efficiency of enterprises' two-stage innovation, but its role in promoting the stage of research and development is more obvious; Organizational inertia and entrepreneurship have a positive moderating effect on the relationship between the two; Further research found that there are regions, urban class and population size, and enterprise nature differences in the impact of digital economy development on the efficiency of two-stage innovation of enterprises.

KEYWORDS

Digital economy; innovation value chain; new energy enterprises; organizational inertia; entrepreneurship

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L22; M13; O30

1. Introduction

The transformation of energy structure is the only way to break the crisis of resource depletion and reduce greenhouse gas emissions. Since China put forward the "double carbon" goal in 2020, the continuous improvement of the "1+N" policies and the release of local carbon peak action plans in seven provinces, including Zhejiang, Sichuan, and Ningxia, have all stressed that the transformation from fossil energy utilization to a large-scale, stable and efficient clean energy system is the only way for China to complete the "30 · 60" goal on schedule. Although China's renewable energy output has the largest increase in history in 2021, the development of new energy is by no means a smooth path, and China lacks deep exploration in the field of new energy technology. At present, a considerable part of high-end components in the field of wind power and photovoltaic are still imported, and because wind power technology cannot be self-sufficient, it can only be imitated by purchasing foreign patents, but subject to patent protection, the products can only be sold domestically. However, several core technology laboratories and production lines supported by national scientific research projects have been dismantled due to insufficient follow-up funds. Breaking through the shackles of weak original technology is the key to the development of new energy industry. New energy enterprises have the characteristics of manufacturing enterprises valuing assets and service enterprises valuing assets. Therefore, with the "acceleration" of digital technology, the digital economy flood will become the core tool to lead the technological innovation of new energy enterprises. It can not only reduce the cost of energy mining, optimize the mining process and improve the recovery efficiency but also bring subversive innovation to distributed energy design, energy trading, and business model. With the

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promotion of China's dual carbon goals, according to the rough statistics of investment projects in 2021 disclosed by listed companies, only 10 billion yuan of new cross-border capital in the photovoltaic field has been invested in the manufacturing end of photovoltaic modules. The fanatical capital expansion undoubtedly poses a major challenge to whether China's new energy industry will move toward low-end overcapacity in the future or "leverage" to achieve deep innovation and transformation.

Therefore, this paper argues that it is necessary to examine the impact of the development of the digital economy on the technological innovation of Chinese new energy enterprises, and if the black box of technology creation is opened under the innovation value chain theory, the digital economy is likely to have different effects on the R&D and results transformation activities of new energy enterprises, and this effect will undoubtedly be influenced by the contextual role of the internal governance environment of enterprises, so it is also necessary to examine the specific manifestations of this effect in different organizational inertia and entrepreneurship contexts.

This paper takes the new energy enterprises listed in A-shares in Shanghai and Shenzhen from 2016–2021 as the research sample, examines the impact of digital economy development on the innovation efficiency of new energy enterprises from the perspective of the innovation value chain, and the regulating role of organizational inertia and entrepreneurship in it. The basic research finds that the development of the digital economy can significantly improve the innovation efficiency of new energy enterprises at the stage of research and development and results transformation. The adjustment effect analysis shows that organizational inertia and entrepreneurship have a significant positive adjustment effect on the relationship between the two. Further analysis shows that in the research and development stage, digital economy development promotes innovation efficiency more strongly in the eastern and western regions, key cities, and state-owned enterprises; in the stage of achievements transformation, digital economy development improves innovation efficiency more significantly in the central and eastern regions, key cities, population size no less than 5 million, and enterprises of state-owned nature.

The research contributions of this paper are as follows: First, the relationship between the urban digital economy and new energy business innovation is poorly documented. Existing research on the digital economy and innovation in high-tech enterprises covers much more than new energy enterprises, so this paper will focus on new energy enterprises to refine the relevant research. Second, if the black box of technology creation is opened under the innovation value chain, the digital economy is likely to have different impacts on the research and development and results transformation activities of new energy enterprises. Based on this, this paper analyzes the impact mechanism of the digital economy on the two-stage innovation efficiency of new energy enterprises and provides a new perspective for the relevant research on technological innovation in the digital economy. Thirdly, the paper introduces organizational inertia and entrepreneurship as the moderating variables, and analyzes the moderating role of organizational inertia and entrepreneurship in the process of the digital economy's impact on the two-stage innovation efficiency of new energy enterprises, in order to clarify whether the moderating effects of the moderating variables are different at different stages.

2. Theoretical Analysis and Research Hypothesis

2.1. Impact of Digital Economy on Innovation Efficiency of New Energy Enterprises

Early scholars regarded high-tech industry innovation activities as a black box and studied the change law of innovation input and output. With the gradual deepening of the research on innovation issues, scholars have realized that innovation is not a single input-output activity. From the perspective of the innovation value chain, technological innovation is a multi-stage activity composed of a series of interrelated sub-processes such as design, research and development, production, and sales (Chen, Liu, and Zhu 2018; Hansen and Birkinshaw 2007; Jiyoung, Chulyeon, and Gyunghyun 2019). Based on the value chain theory, Guan and Chen (2010) divide the process of technological innovation in high-tech industries into two stages: research and development and results transformation. With the focus on research from industrial innovation to the firm level, some scholars have measured the two-stage innovation efficiency of high-tech firms based on the innovation value chain perspective (Ganotakis and Love 2012; Koellinger 2008).

According to the theory of environmental adaptation, in order to achieve sustainable operation, enterprises must respond to the drastic changes in the external environment in time and integrate into the new environment. Therefore, in the era of the digital economy, the development of the digital economy will inevitably have an impact on the innovation of new energy enterprises. As an extension of the information economy and Internet economy, the impact of the digital economy on high-tech industry innovation is inseparable from the development of information and the Internet. At the initial stage, scholars found that the improvement of informatization level can significantly improve the efficiency of high-tech industry innovation, and it can promote the transformation of high-tech enterprise innovation systems from "building cars behind closed doors" to "mass innovation" by reducing transaction costs (Mahr and Lievens 2011; Ravichandran, Han, and Mithas 2017). After that, the application of the Internet has made great strides forward. Internet technology can promote innovation investment and improve the innovation performance of high-tech industries by playing its role as an efficient information transmission medium (Kleis et al. 2012). But there're research shows that high-tech enterprises' technological achievements are based on the development and integration of cutting-edge technologies, and the high profits brought by technological monopoly make high-tech enterprises choose to "keep silent" on the Internet (Yang and Wang 2021). Relying on the scientific and technological achievements brought about by the Internet revolution, AI technology has become increasingly mature. Compared with labor-intensive industries in order to reduce labor costs, high-tech industries seek to improve R&D efficiency and respond to market demand through AI, so their integration with AI is deeper. It has been pointed out that the use of AI can reduce the marginal cost of research and development, increase the number of highly skilled labor, promote the training of enterprise employees, and improve the technological innovation effect of high-tech industries (Benzell et al. 2015; Cockburn, Henderson, and Stern 2018; Sung and Choi 2014). In recent years, digital applications have emerged in an endless stream, and the combination of virtual and real in the economic field has brought forth new ideas. The innovation-driven effect of the digital economy has attracted extensive attention from scholars. The study found that the digital economy can not only promote the innovation efficiency of high-tech industries but also have obvious regional and industrial heterogeneity (Lin et al. 2021). This paper focuses on new energy enterprises and divides technological innovation into two stages: research and development and results transformation stages, which help to reveal the source of digital economy dividends behind enterprise innovation while refining relevant research.

The research and development stage aims to realize the transformation of R&D resources into scientific and technological achievements. According to previous studies, the high R&D costs and financing constraints caused by the characteristics of high investment, long cycle, and high risk of R&D activities and the "quasi-public goods" attribute of clean energy make new energy enterprises choose to give up increasing R&D investment in the balance of interests (Zhou et al. 2015). In the development of the digital economy, as an open and shared high-quality resource gathering place, new energy enterprises can obtain innovative resources at a very low cost. In addition, digital communication and network transactions replace the common, real-time and accurate interactive way of obtaining information in traditional ways, which rapidly reduces the technical threshold and access cost of their business ecosystem (de Faria, Lima, and Santos 2010). Additionally, the digital economy has enhanced the ability of financial institutions to obtain and process information. It can not only expand the financing channels of new energy enterprises by integrating and absorbing scattered funds but also alleviate the distortion of credit resource allocation by optimizing the credit risk assessment system, reducing the lending threshold of new energy enterprises, and promoting research and development investment. The interdisciplinary and interdisciplinary nature of new energy technology makes it highly demanding to achieve industry-university-research cooperation and the ability of enterprises to cooperate in all aspects. Among the participants in the research and development of new energy patents, only the field of solar technology has formed a comprehensive research and development system with research institutions and domestic and foreign enterprises, while wind energy, fuel cells, and other energy technology research and development systems that have not yet realized the close integration of enterprises, universities and research institutions (Ma and Liu 2017). The efficiency of technology flow brought by traditional resource flow is low. With the help of digital innovation platforms, the cost of information search and communication among partners has significantly decreased (Soto-Acosta, Popa, and Martinez-Conesa 2018). The formal and informal exchanges between enterprises and universities and scientific research institutions will be more frequent. In the process of information fusion and collision, a large number of innovative elements such as knowledge and human resources will overflow into enterprises, forming the source of innovative ideas. Moreover, the vertical organization of energy in China has information barriers, and the degree of interdependence and internal and external economic links between production, transmission, and consumption are insufficient. Meanwhile, the comprehensive management of various forms of renewable energy use lacks "multi-source complementarity", and horizontal interconnection is difficult to achieve. The vertical and horizontal barriers hinder the coordinated integration of various actors and links in the process of research and development. However, the digital economy integrates diversified enterprises, including upstream and downstream of the industrial chain, into the digital ecological network by means of virtual agglomeration, especially with the rise of the energy internet in recent years. With the help of the digital ecological network, it can deepen the collaborative cooperation among the key links of innovation, and strengthen the flexibility of enterprise R&D system and the collaborative ability of the supply chain (Bui et al. 2012, 2018; Lanzisera et al. 2014). For example, in 2020, Ningxia Electric Power and State Grid Electric Commerce Co., Ltd. jointly applied for the first licensed patent in the new energy power industry based on blockchain technology in China, breaking the technical gap in this field [website https://www.yicai.com/news/100836852.html].

In the results transformation stage, enterprises further transform the knowledge they create into products or services to achieve innovation performance. The study pointed out that the new energy industry only relies on supply-side resources to promote the supply of knowledge and technology, which can only lead to the overcapacity of homogeneous products (Edquist and Hommen 1999). In 2021, the wind and light abandonment rates in northwest China, where the problem of new energy consumption is the most serious, are 5.2% and 5.8% [the data comes from the National Monitoring and Warning Center for New Energy Consumption], which has been significantly improved compared with the 13th Five-Year Plan period. However, the pressure of new energy utilization under the traditional large-scale development mode has weakened the power of enterprises to carry out results transformation for a long time, and the development of the digital economy will promote results transformation from both supply and demand sides. The open innovation brought by the digital economy can accurately perceive the needs and preferences of new energy customers. On this basis, the use of big data to deduce and analyze market demand will help enterprises identify new growth points of user value and the best path for technological innovation succession. Furthermore, consumers use the Internet and e-commerce platform to significantly reduce the cost of product search and matching, and the fierce market competition strengthens the rule of survival of the fittest, forcing enterprises to carry out market-oriented innovation activities. The business model of the energy industry has a natural "monopoly" trend and will form a countervailing effect, which undoubtedly weakens market competition and reduces the motivation of enterprises to commercialize. In addition, the long-standing natural and institutional market segmentation problems such as the unsmooth energy trans-provincial transaction mechanism have significantly reduced the market value of new products and new technologies. Therefore, the new energy industry must join in the flood of business model innovation. Based on the digital trading platform, the trading of new energy products can break through the boundaries of the provincial market and give full play to the potential of domestic demand by relying on the integrated supermarket volume. At present, the central energy enterprises are focusing on promoting the “energy Taobao” business, such as Energy No.1, Guoneng e-Shopping Mall, and Yipaike, which can realize the B2C and C2C modes of energy trading. Finally, foreign trade is also an important part of the transformation of innovative achievements of new energy enterprises. However, in recent years, the adverse trend of trade protectionism, as well as the global economic shocks caused by COVID-19 since 2020, have all impacted the new energy foreign trade market.

Under the role of the digital economy, it can enhance the willingness to trade in the foreign trade market by breaking geographical barriers, reducing delivery and regulatory costs, and increasing the diversification of products and markets. Moreover, the digital economy is conducive to fostering customer communities. Enterprises can display goods to overseas consumers through cross-border e-commerce platforms, and rely on the “scene+product” strategy of the digital platform to conduct remote interaction, build trust and achieve cooperation. Taking Shenzhen Huabao New Energy Enterprise, the leader in the field of energy storage, as an example, in 2021, the company’s online sales on well-known e-commerce platforms at home and abroad, such as Amazon, Yahoo, JD, etc., accounted for 68.89% of its main business income and was successfully listed on the GEM of Shenzhen Stock Exchange in March 2022. Accordingly, the following assumptions are proposed in this paper:

H1: The development of digital economy will help improve the efficiency of two-stage innovation of new energy enterprises.

2.2. The Moderating Effect of Organizational Inertia

Organizational inertia is an important variable that affects the orientation and implementation of enterprise innovation decision-making (Tushman and Romanelli 1985). The stability and efficiency of organizational operation brought by certain organizational inertia is the cornerstone of enterprise technological innovation. In the complex and volatile innovation system of the digital economy, in order to adapt to the turbulent environment and respond to the task impact in a timely manner, new energy enterprises need to rely on the early organizational structure, customary systems, and advanced evolution of knowledge and experience to pursue new knowledge and reconstruct new digital capabilities. For the stage of research and development, the rapid application of digital technology will lead to the influx of excessive information and increase the complexity of research and development activities. The high level of organizational inertia helps new energy enterprises quickly identify scarce innovation resources. Enterprises tend to communicate and cooperate with specific innovation entities, ensuring the effective and reliable sources of technical knowledge. Certain organizational inertia means that the stock, skills experience has been accumulated to a certain extent, which meets the demand of R&D resource integration of new energy enterprises in the digital economy. For the results transformation stage, certain organizational inertia means that new energy enterprises have established long-term and stable good cooperation with enterprises upstream and downstream of the industrial chain, which is conducive to reducing search costs, reducing organizational conflicts and internal consumption (Shi and Zhang 2018), helping the digital economy to achieve supply chain coordination and control, and improving production efficiency. The accumulated, reliable and useful information constitutes the basic element of combining new products and services in the business model innovation of new energy enterprises driven by the digital economy. In addition, new energy enterprises are extremely vulnerable to the impact of the macroeconomic environment or industrial policies. Achievements with inertia characteristics are transformed in the way of asymptotic exploration, which has the space to cope with the impact and can stop losses in time, greatly avoiding the market risks brought about by customer demand, product substitution, macro policy changes, etc. Accordingly, the following assumptions are proposed in this paper:

H2: Organizational inertia can positively moderate the effect of the digital economy on the two-stage innovation efficiency of new energy enterprises.

2.3. The Moderating Effect of Entrepreneurship

The core of entrepreneurship is the embodiment of the comprehensive qualities of enterprise managers in carrying out innovation activities, such as organizational preparation, crisis response, decision-making sensitivity, and risk-taking (Lyu et al. 2020). For the R&D stage of science and technology, entrepreneurship is the structural factor of open innovation. It extends the innovation activities of enterprises through the digital economy to the supply chain network embedded in enterprises and realizes the "curve overtaking" of patented technology by imitating the R&D mode of advanced enterprises. The entrepreneurial spirit is rich in organizational preparation, crisis management, and response capabilities, which enable it to flexibly thread the needle when facing various innovation subjects, maximize the integration and distribution of innovation resource, and promote the orderly conduct of industry-university-research activities (Shane and Ulrich 2004). For the results transformation stage, the innovation sensitivity and decision-making ability contained in entrepreneurship help enterprises identify the potential market value contained in research and development achievements, promote new energy enterprises to use digital technology tools to conduct research and prediction of market information, mass produces new products with market prospects, and improve the economic value and market recognition of products (Yunis, Tarhini, and Kassar 2018). The entrepreneurial spirit has the courage to take risks, so that it is not afraid of failure, and dare to use the digital economy to constantly pursue the renewal of business models, in order to obtain income flow and business. Accordingly, the following assumptions are proposed in this paper:

H3: Entrepreneurship can positively moderate the effect of digital economy on the two-stage innovation efficiency of new energy enterprises.

3. Research Design

3.1. Variable Selection and Calculation

3.1.1. Explained Variable

In view of the multiple input and multiple output efficiency and the different scale of listed companies involved in this paper, in order to better reflect and compare the innovation efficiency of enterprises, refer to the research of Tone and Tsutsui (2008), we use the non-radial, variable return to scale, and input-oriented two-stage associated network DEA model, and use MaxDEA software to calculate the

Table 1. Two-stage innovation efficiency evaluation index system.

Technological innovation stage	Indicator type	Indicator name
Research and development stage	Input indicators	R&D expenditure
		Number of R&D personnel
	Output indicators	Number of invention patent applications
		Total intangible assets
Results transformation stage	Input indicators	Number of invention patent applications
		Total intangible assets
	Output indicators	Business income
		Net profit

Table 2. Evaluation index system of China's urban digital economy development level.

First-level indicators	Secondary indicators	Indicator attribute
Digital finance	China Digital Finance HP Development Index	+
Internet economic benefits	Per capita telecom business income	+
Digital application talents	Number of employees in information technology services and software	+
Informatization level	Number of Internet broadband users	+
Digital infrastructure	Number of mobile phone users	+

innovation efficiency (TE^1) and the innovation efficiency (TE^2) in the research and development stage of new energy enterprises. The specific input-output indicators are shown in Table 1.

3.1.2. Explanatory Variables

At present, academic circles measure the development level of the urban digital economy (*Digital*) mainly from the following two perspectives: First, learn from the research of Zhao, Zhang, and Liang (2020) on the measurement of the digital economy. The second is to measure the development level of the digital economy by using the urban digital economy indicator system issued by domestic authoritative digital economies research institutions, such as Tencent Research Institute and New Sanhua Group Digital Economy Research Institute. In consideration of the availability of data and to ensure a certain research period, this paper follows the practice of Zhao, Zhang, and Liang (2020), and uses the principal component analysis method to calculate the comprehensive value to measure the level of urban digital economy based on the five indicators of digital finance, Internet economic benefits, digital application talents, informatization level and digital infrastructure. The specific indicators are shown in Table 2:

3.1.3. Moderating Variables

For the measurement of organizational inertia (*OI*) and entrepreneurship (*ES*), the entropy weight method is used to determine the index weight, and then weighted to obtain comprehensive indicators to measure. The indicators used are shown in Table 3.

3.1.4. Control Variables

We can select the control variables at the enterprise and city levels. Enterprise size (*Size*). It is measured by the logarithm of the total assets of the enterprise at the end of the period; Enterprise age (*Age*). It is measured by logarithm of the establishment time of the enterprise; Return on assets (*Roa*). It is measured by the ratio of net profit to total assets at the end of the period; Asset-liability ratio (*Dar*). It is measured by the ratio of total liabilities at the end of the period to total assets at the end of the period, fixed asset ratio (*Fix*). It is measured by the ratio of the net fixed assets at the end of the period to the total assets at the end of the period; Administrative expenses (*Manage*). It is measured by the ratio of enterprise management

Table 3. Comprehensive evaluation index system of organizational inertia and entrepreneurship.

First-level indicators	Secondary indicators	Indicator meaning	Indicator attribute
Organizational inertia	Number of employees	Number of employees in the current year	+
	Enterprise market value	Total market value of enterprises at the end of the period	+
	Total assets	Total assets at the end of the period	+
	Registered capital	Total registered capital of the enterprise	+
Entrepreneurship	Number of enterprise patent applications	Total number of enterprise patent applications (including invention patents, utility model patents and design patents)	+
	Fixed assets per capita	Net fixed assets/number of employees at the end of the period	+
	Per capita income	Payroll payable/number of employees	+
	Intangible assets per capita	Net intangible assets/number of employees at the end of the period	+
	Independence of the Board of Directors	Number of independent directors/total number of directors	+

expenses to operating income; Financial development level (*Finance*). It is measured by the ratio of total deposits and loans of financial institutions to urban gross domestic product; City size (*People*). It is measured by the logarithm of the number of urban employees.

3.2. Data Description

Since the number of research and development personnel of listed companies has not been officially disclosed before 2016, the research period of this paper is 2016–2021. The new energy enterprises listed in A-shares of Shanghai and Shenzhen stock markets are selected as the research samples. Based on the listed enterprises in the new energy concept section of mainstream financial websites such as Tonghuashun, the investment-oriented enterprises engaged in the development of new energy projects, and the financial situation is abnormal (ST, * ST). The panel data of 56 new energy companies with a total of 336 observation samples were finally selected for enterprises listed after 2016, enterprises with scattered or changed registered places, and enterprises with missing or negative financial indicators (such as main business income, management expenses, etc.). The enterprise-level data is obtained from CSMAR database and Wind database, and supplemented by the annual report of listed companies on http//www.cninfo.com.cn. The sample data at the city level are from the China Urban Statistical Yearbook, the EPS database, and the statistical bulletins of various cities. Individual missing data are filled by interpolation method. In order to ensure the validity and consistency of the model estimation, this paper has carried out Winsor processing on all continuous variables at the upper and lower levels of 1%, and normalize both variables before constructing the interaction term by subtracting the mean of that variable from each variable to reduce multicollinearity between that variable and the interaction term.

3.3. Model Setting

In order to test the impact of the development of urban digital economy on the innovation efficiency of new energy enterprises in the research and development stage and the results transformation stage, This paper relies on Zhang et al. (2015) approach to construct a panel Tobit model for benchmark regression analysis for efficiency values between 0 and 1. This paper uses Stata (MP14.0) software, the results of the LR test statistic were 58.05 for the science and technology R&D stage and 146.03 for the results transformation stage, both of which rejected the hypothesis of no individual effect at the 1% significance level. so this paper selects the panel Tobit model with random effects as follows:

$$TE^{j}_{i,t} = C + \alpha_1 Digital_{i,t} + Controls_{i,t} + \varepsilon_{i,t} \tag{1}$$

In the formula, $TE^{j}_{i,t}$ represents the innovation efficiency of new energy enterprises, $j = 1, 2$, respectively representing the innovation efficiency in the R&D stage and the innovation efficiency in the results transformation stage. $Digital_{i,t}$ refers to the year of t digital economic development level of the city where the company is registered, and $Controls_{i,t}$ refers to the year of t control variables at the level of enterprises and cities, $\varepsilon_{i,t}$ is a random error item.

On this basis, in order to examine whether organizational inertia and entrepreneurship play a moderating role in the process of the impact of urban digital economy on the two-stage innovation efficiency of new energy enterprises, the interaction of organizational inertia, entrepreneurship and urban digital economy development is introduced to build a model, as follows:

$$TE^{j}_{i,t} = C + \beta_1 Digital_{i,t} + \beta_2 OI_{i,t} + \beta_3 OI_{i,t} \times Digital_{i,t} + Controls_{i,t} + \varepsilon_{i,t} \tag{2}$$

$$TE^{j}_{i,t} = C + \gamma_1 Digital_{i,t} + \gamma_2 ES_{i,t} + \gamma_3 ES_{i,t} \times Digital_{i,t} + Controls_{i,t} + \varepsilon_{i,t} \tag{3}$$

In the formula, $OI_{i,t}$ and $ES_{i,t}$ respectively represent the organizational inertia and entrepreneurship of the moderating variables, β_3 and γ_3 are the key coefficients to test the moderating effect. The other variables have the same meaning as the model (1).

4. Analysis of Empirical Results

4.1. Descriptive Statistics

The descriptive statistics of the variables are shown in Table 4, where the average of the innovation efficiency of research and development (TE^1) is 0.3797, and the achievement conversion rate (TE^2) is 0.0661, indicating that the innovation efficiency of the research and development stage of new energy enterprises is significantly higher than that of the achievement conversion stage; The minimum value of digital economy (*Digital)* is 8.1788, the maximum value is 12.8032, and the standard deviation is 1.1289, which means that there is a certain gap in the development level of digital economy in different cities at present; The standard deviation of organizational inertia (*OI*) and entrepreneurship (*ES*), the moderating variables, was 2.3518 and 1.5035, respectively, which was larger than that of other variables, indicating that there were significant differences in organizational inertia and entrepreneurship levels among different enterprises; The descriptive statistical results of the control variables are basically consistent with the existing research results, and will not be repeated here.

4.2. Benchmark Regression Results

Table 5 reports the impact of the development of urban digital economy on the two-stage innovation efficiency of new energy enterprises, in which columns (1) and (4) are the estimated results that only contain the core explanatory variable Digital, and the rest are the regression results that gradually add

Table 4. Descriptive statistics analysis.

Variable	Observations	Mean	sd	Min	Max
TE^1	336	0.3797	0.3354	0.0003	1.0000
TE^2	336	0.0661	0.1976	0.0002	1.0000
Digital	336	10.8002	1.1289	8.1788	12.8032
OI	336	−3.7618	2.3518	−12.4898	2.7807
ES	336	−2.0870	1.5035	−6.4001	1.6501
Size	336	23.0594	1.3461	20.1537	27.5469
Age	336	18.6071	5.0691	7.0000	36.0000
Roa	336	0.0336	0.1843	−1.6898	0.3323
Dar	336	0.5049	0.1648	0.0948	0.9360
Fix	336	0.2493	0.1445	0.0055	0.6682
Manage	336	0.0924	0.0595	0.0106	0.5927
Finance	336	1.8176	0.5155	0.5619	5.3046
People	336	5.5076	0.9518	2.7750	6.8945

Table 5. Regression results of benchmark model.

	Research and development stage			Results transformation stage		
Variable	(1)	(2)	(3)	(4)	(5)	(6)
Digital	0.1135***	0.1334***	0.1890***	0.0336*	0.0249*	0.0623*
	(1.83)	(2.02)	(2.73)	(1.90)	(1.88)	(1.71)
Constant	−0.1029	−2.0794***	−2.5104***	−0.2957	−2.1300***	−2.3331***
	(−0.28)	(−3.12)	(−3.43)	(−1.54)	(−7.10)	(−6.96)
Company Controls	No	Yes	Yes	No	Yes	Yes
Industry Controls	No	No	Yes	No	No	Yes
Obs	336	336	336	336	336	336

Note: ***, **, * are significant at the significance level of 1%, 5%, and 10%, respectively, Z-values are in parentheses. Due to space limitations, only the regression results of the most important explanatory variables are reported, the following table is the same.

the control variables at the enterprise and city levels. It can be seen from the results that, under the control of enterprise and city variables, the digital economy has significantly improved the innovation efficiency of new energy enterprises at the stage of research and development and results transformation at the level of 1% and 10% respectively, verifying H1.

It is worth noting that the digital economic regression coefficient (0.0623) in the results transformation stage is far less than the coefficient in the research and development stage (0.1890). The insufficient transformation of technological achievements in China has been a repeat of the old story (internal transformation will, absorptive capacity, external policies and systems, etc (Marjorie et al. 1996; Schulz 2001)), and has not been fundamentally improved. In addition, compared with research and development, it is faced with large investment costs, promotion costs and other sunk costs, and the types of risks are more diverse and complex. It is necessary to establish the optimal combination of elements of the digital economy, as well as various management systems and rules such as collection and circulation trading rules and data security rules that match the development of the digital economy, so as to achieve a targeted goal. At present, the development of China's digital economy is mainly oriented toward the field of terminal consumption, and the degree of digitalization at the supply end is relatively weak, which leads to high cost of enterprise trial and error and the conversion cost of offline and offline channel migration. Moreover, with the support of the incentive policies such as preferential access to new energy, the traditional channel can still maintain a certain profit. Therefore, enterprises are lack of endogenous power in applying digital technology to promote the transformation of achievements. Among the control variables, the impact of enterprise size and management costs on the efficiency of research and development and results transformation stages is significantly positive, indicating that it has a promoting effect on the two-stage innovation of new energy enterprises. The technological base, innovation resources and risk resistance of large enterprises are the prerequisites for gaining innovative advantages, while overhead costs reflect the readiness and complexity of the innovation organization, which can undoubtedly enhance the innovative strength of new energy enterprises.

4.3. Moderating Effect Test

Table 6 reports the results of the moderating effect test. Column (1) and column (2) are the regression results with organizational inertia as the moderating variable. It can be seen that organizational inertia significantly positively moderates the relationship between the digital economy and the innovation efficiency of new energy enterprises in the two stages at the level of 5% and 1%, respectively, in the stage of research and development and results transformation. H2 has proved that. When an enterprise is in a high-risk, long-cycle technological innovation activity and a complex and volatile digital economy development environment, it is difficult to fully realize the exploration value of the application of digital technology, while the conservative "customary compliance" provides rich

Table 6. Test results of moderating effect.

	Organizational inertia			Entrepreneurship	
Variable	Research and development stage (1)	Results transformation stage (2)	Variable	Research and development stage (3)	Results transformation stage (4)
Digital	0.3194***	0.1456***	Digital	0.1522**	0.0319*
	(3.56)	(3.33)		(2.35)	(1.88)
OI	−0.3173**	−0.2170***	ES	0.1966***	0.1144***
	(−2.32)	(−3.27)		(7.24)	(7.56)
Digital × OI	0.0281**	0.0192***	Digital × ES	0.0027***	0.0015***
	(2.34)	(3.39)		(5.43)	(5.12)
Constant	−3.9074***	−3.1490***	constant	−0.1105	−0.1114
	(−2.99)	(−4.81)		(−0.26)	(−0.52)
Controls	Yes	Yes	controls	Yes	Yes
Obs	336	336	Obs	336	336

resources and knowledge reserves for the integration of the research and development stage of new energy enterprises and the digital economy, and provides a mature supply chain business process and operation mode for the results transformation stage. It is beneficial for the digital economy to play a positive role in the two-stage innovation efficiency of new energy enterprises.

Column (3) and column (4) are the regression results with entrepreneurship as the moderating variable. The results show that entrepreneurship positively moderates the impact of digital economy on the two-stage innovation efficiency of new energy enterprises at the 1% significance level. By giving full play to their subjective initiative, entrepreneurs have not only become the first promoters of innovation practice in the digital economy, but also their ability to identify and use R&D resources, and their accuracy in grasping the innovation dynamics of products and services in the new energy industry will be transformed into decision guidance, which will promote the evolution of innovation activities of new energy enterprises in the digital economy from superficial innovation resource combination to deep resource arrangement.

In addition, this paper draws the moderating effects of organizational inertia and entrepreneurship. Figures 1 and 2 show the moderating effect of organizational inertia. Figure 1 shows that in the stage of research and development, the impact of digital economy on the innovation efficiency of enterprises is greater than that of low organizational inertia. That is, the higher the level of organizational inertia of

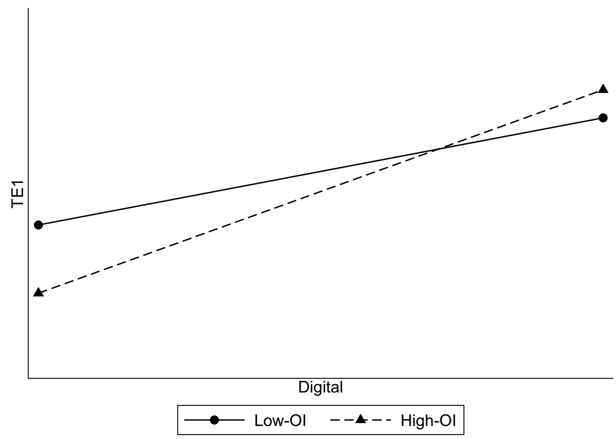

Figure 1. The moderating effect of organizational inertia in research and development stage.

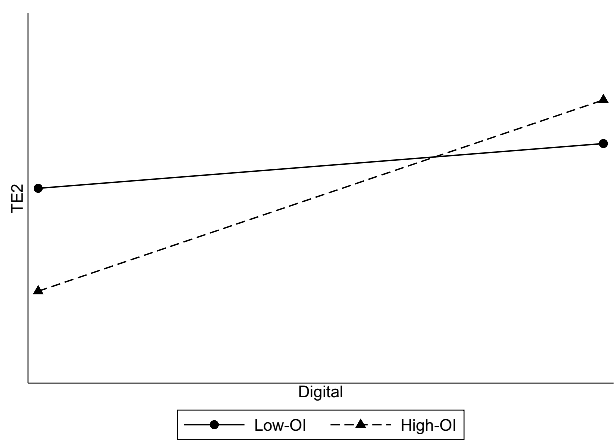

Figure 2. The moderating effect of organizational inertia in results transformation stage.

enterprises, the greater the positive moderating effect of digital economy, and the more conducive to the technological research and development of new energy enterprises. Figure 2, at the stage of results transformation, organizational inertia also shows the same moderating effect, that is, the higher the level of organizational inertia of enterprises, the stronger the promotion effect of digital economy on the efficiency of results transformation of new energy enterprises; Figures 3 and 4 show the moderating effect of entrepreneurship. In the stage of research and development, the slope of the moderating effect map in the context of high-level entrepreneurship is steeper, indicating that entrepreneurship has to some extent enhanced the role of digital economy in improving the efficiency and efficiency of enterprise research and development. Figure 4 at the stage of results transformation, entrepreneurship also positively moderated the relationship between the digital economy and the efficiency of results transformation of new energy enterprises. The results of the diagram also verified H2 and H3 again.

4.4. Robustness Test

First, considering that there may be endogenous problems caused by two-way causality between enterprise innovation and the digital economy, this paper uses the instrumental variable Tobit method (IVTobit) to select the interaction between the number of fixed phones per 100 people

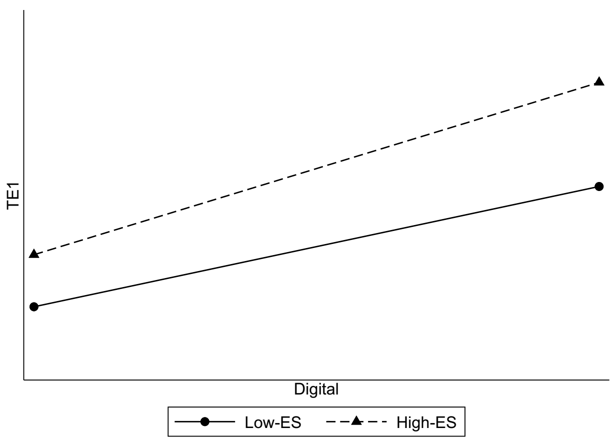

Figure 3. The moderating effect of entrepreneurship in research and development stage.

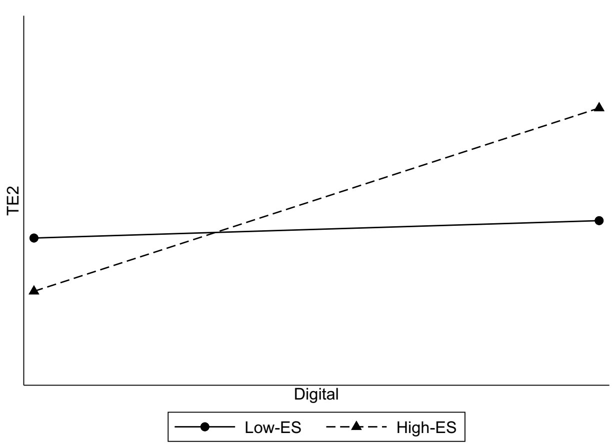

Figure 4. The moderating effect of entrepreneurship in results transformation stage.

in each city in 1984 and the annual national information technology service income as the instrumental variable (IV) of the digital economy. The digital economy as a continuation of the development of traditional communication technology, and the local history of telecommunications infrastructure represented by fixed-line telephony will influence the subsequent development and application of the digital economy in terms of technology, scale, and usage habits to meet the relevance. Meanwhile, the impact of traditional telecommunications tools, such as landline telephones, on technological innovation is diminishing as frequency of use declines to meet exclusivity. However, the number of landlines is cross-sectional and cannot be used for empirical analysis of panel data, so we refer to the study by Nunn and Qian (2014) and introduce a time-varying interaction term between national IT service revenues and the number of landlines per 100 people in 1984 as an instrumental variable. Columns (1) and (3) of Table 7 report the regression results of IVTobit at the stage of scientific research and technological development and results transformation. It can be found that the impact of the digital economy on the two-stage innovation efficiency of new energy enterprises is consistent with the benchmark analysis results.

Second, this paper further uses the random effect model (RE) to prove the robustness of Tobit model. The regression results are shown in columns (2) and (4) of Table 7. In the two stages of innovation, the coefficients and symbols of Digital have not changed significantly, and both have passed the 10% significance test. The research conclusion is reliable.

Thirdly, this paper also tests the robustness of the results of the moderating effect. Considering the long cycle of innovation activities and the possibility of time lag, this paper incorporates the two-stage innovation efficiency variable with one lag into model (2) and model (3) for regression. The estimated results are shown in columns (1) to (4) of Table 8. It can be seen that the moderating effect test results are consistent with the above, and the research conclusion is reliable.

Fourth, after removing 3% of the samples of the maximum and minimum values of the efficiency of the research and development stage, the efficiency of the results transformation stage, the organizational inertia and entrepreneurship, the model (2) and model (3) are regressed, and the estimated results are shown in columns (5) to (8) of Table 8. The moderating effect coefficients of organizational inertia and entrepreneurship in the two stages of innovation are significantly positive, which verifies the robustness of the regression results.

5. Further Study

Considering that the impact of the digital economy on the efficiency of enterprise innovation may exist in the heterogeneity of enterprise micro-characteristics and external environment (Guan and

Table 7. Results of robustness test: benchmark regression.

	Research and development stage		Results transformation stage	
	IVTobit	RE	IVTobit	RE
Variable	(1)	(2)	(3)	(4)
Digital	0.1964***	0.1536*	0.0290*	0.0286*
	(3.33)	(1.81)	(1.95)	(1.92)
Constant	−1.5611**	−2.0768**	−0.3644**	−2.1278***
	(−1.98)	(−2.50)	(−2.11)	(−2.99)
Controls	Yes	Yes	Yes	Yes
Wald test	67.18***		77.70***	
AR	88.74***		129.37**	
Obs	336	336	336	336

Note: The Wald exogeneity test at both stages rejects the original hypothesis at the 1% level of significance, indicating that the digital economy is endogenous. The original hypothesis is rejected, indicating that there is no "weak instrumental variable" problem. The instrumental variable regression results in this study are valid.

Table 8. Results of robustness test: moderating effect.

	Organizational inertia (The interpreted variable lags behind)		Entrepreneurship (The interpreted variable lags behind)		Organizational inertia (excluding 3% extreme value)		Entrepreneurship (excluding 3% extreme value)	
Variable	Research and development stage (1)	Results transformation stage (2)	Research and development stage (3)	Results transformation stage (4)	Research and development stage (5)	Results transformation stage (6)	Research and development stage (7)	Results transformation stage (8)
Digital × OI	0.0341**	0.0150**			0.0291**	0.0216***		
	(2.54)	(2.48)			(2.24)	(3.56)		
Digital × ES			0.0403***	0.0284***			0.0280*	0.0350***
			(3.17)	(4.17)			(1.96)	(4.54)
Constant	−2.7138*	−1.2103*	−1.2307**	−1.2574***	−3.9319***	−3.2649***	−1.2379**	−1.4246***
	(−1.82)	(−1.71)	(−2.30)	(−4.58)	(−3.03)	(−5.08)	(−2.26)	(−4.92)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	336	336	336	336	336	336	336	336

Table 9. Regression results of regional heterogeneity.

	Research and development stage			Results transformation stage		
Variable	East (1)	Middle (2)	West (3)	East (4)	Middle (5)	West (6)
Digital	0.1846**	0.0394	1.1986***	0.0525**	0.2817**	−0.0222
	(2.39)	(0.24)	(4.51)	(2.18)	(1.98)	(−0.35)
Constant	−2.4641***	−9.5453***	−9.9433***	−1.6981***	−5.1639***	−0.7352
	(−3.17)	(−3.06)	(−4.85)	(−2.79)	(−4.11)	(−1.15)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Obs	216	72	48	216	72	48

Chen 2012; Hashimoto et al. 2008), this paper further divides samples according to geographical location, urban class and population size, and enterprise nature to conduct heterogeneity analysis.

First, regional heterogeneity. In this paper, the whole sample is divided into three regions: east, west, central, and the results are shown in Table 9. For the R&D stage of science and technology, the development level coefficient of digital economy in the eastern and western regions is significantly positive, indicating that the development of digital economy can effectively promote the innovation efficiency of new energy enterprises in the R&D stage of science and technology, and has a stronger role in promoting enterprises in the western region, while the R&D driving role of the digital economy in the central region is not significant. The possible reason is that compared with the central region, the development of the digital economy in the eastern region has entered a stable and large-scale development stage, and its application depth and breadth can bring effective impetus to the research and development of new energy enterprises. For the western region, it has the late-development advantage of patent technology, which is an important channel for the digital economy to improve the research and development level of new energy enterprises. Moreover, as an important new energy base in China, the development volume of renewable energy such as solar energy can account for more than 48% of the total opening volume of the country (the data comes from the STATE GRID Corporation of China.), so the R&D driving effect of the digital economy has the largest space in the western region.

For the results transformation stage, the digital economy in the eastern and central regions has significantly improved the innovation efficiency of new energy enterprises, while the promotion role of the western region does not exist. The reason is that the location advantage of "connecting the east and opening the west" in the central region is conducive to creating a new type of cross-regional collaborative cooperation. Relying on the digital economic advantages such as the top node of Wuhan Industrial Internet, a network of results transformation channels is formed in all directions. However, the environmental atmosphere and awareness of the results transformation of new energy enterprises in the western region are weaker than those in the eastern and central regions, and the subjective will to realize the transformation is not strong. In addition to the "digital gap" with developed regions, some technologies can only be "shelved".

Second, the analysis of the heterogeneity of urban class and population size. This paper divides the whole sample into key cities and general cities according to whether it is a provincial capital, municipality directly under the Central Government and sub-provincial cities. The regression results of the two types of samples are shown in columns (1) to (4) of Table 10. It can be found that in the development of digital economy in key cities, the innovation efficiency of new energy enterprises in both phases has been significantly improved, but it has not shown a substantial innovation-driven effect in general cities. The "siphon effect" of digital industry in key cities further aggravates the development gap between general cities and their digital economy, which is prone to polarization. Furthermore, the special status and responsibilities of key cities within the province have given them a stronger impetus to enhance research and development through the digital economy and promote the transformation of achievements, and the administrative level directly affects the production efficiency of enterprises (Jiang, Sun, and Nie 2018). The higher productivity under the high administrative level effectively accelerates the implementation speed of enterprise results transformation in

Table 10. Regression results of urban class and population size heterogeneity.

	Research and development stage		Results transformation stage		Research and development stage		Results transformation stage	
Variable	Key cities (1)	General cities (2)	Key cities (3)	General cities (4)	Population ≥ 5 million (5)	Population < 5 million (6)	Population ≥ 5 million (7)	Population < 5 million (8)
Digital	0.2675***	−0.0435	0.1032**	−0.0080	0.3158***	0.1662**	0.1356**	−0.0250
	(3.14)	(−0.43)	(2.18)	(−0.93)	(2.93)	(2.35)	(2.32)	(−0.62)
Constant	−3.2980***	−2.9493**	−2.8488***	−0.0170	−1.3319	−4.2403***	−3.1775***	−1.1168***
	(−3.70)	(−2.11)	(−6.55)	(−0.17)	(−1.03)	(−3.04)	(−5.17)	(−2.83)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	264	72	264	72	186	150	186	150

Table 11. Regression results of enterprise ownership heterogeneity.

	Research and development stage		Results transformation stage	
Variable	state-owned(1)	Non-state(2)	state-owned(3)	Non-state(4)
Digital	0.2744**	0.1032	0.1364**	0.0264
	(2.15)	(1.21)	(2.12)	(0.63)
Constant	−2.2072*	−3.1403***	−2.3709***	−2.1242***
	(−1.94)	(−3.01)	(−4.21)	(−5.06)
Controls	Yes	Yes	Yes	Yes
Obs	144	192	144	192

the digital economy. However, in general cities, due to the insufficient development of hardware construction and software environment of the digital economy and the relative shortage of innovation resources, the "innovation compensation" is less than the "compliance cost", which hinders the promotion of the digital economy on the efficiency of two-stage innovation.

In order to examine the differential impact of urban digital economy on the two-stage innovation efficiency of new energy enterprises under different population sizes, this paper divides and regresses the entire sample with the permanent resident population of 5 million urban areas as the dividing line. The results from columns (5) to (8) of Table 10 show that the digital economy can effectively improve the innovation efficiency of new energy enterprises in cities with different population sizes at the R&D stage, but the impact of the digital economy on innovation efficiency is not significant in cities with a population size of less than 5 million at the results transformation stage. The small population size means that the size of the labor market and the potential demand of the consumer market are small, which undoubtedly weakens the human capital accumulation and power of the digital economy to promote the transformation of new energy enterprises.

Third, the analysis of enterprise ownership heterogeneity. Table 11 shows the regression results of urban digital economy on the two-stage innovation efficiency of new energy enterprises with different ownership. The results show that the development of digital economy has only significantly promoted the two-stage innovation efficiency of state-owned new energy enterprises. For state-owned enterprises, they play a leading role in the development of China's energy industry. Therefore, compared with non-state-owned enterprises, they will be under greater public pressure. They need to use the digital economy to improve their innovation performance to respond to social expectations. At the same time, the natural political connection between state-owned enterprises and the government makes it easier to obtain loose budget constraints and implicit subsidies, and it is easier to use the digital economy to obtain resources to form innovative advantages. For non-state-owned enterprises, they face obvious "ownership discrimination" and "scale discrimination" in commercial bank loans. Considering the insurmountable constraints of innovation financing and conversion costs, it is difficult for the digital economy to make disruptive progress in enterprise innovation.

6. Conclusion and Enlightenment

6.1. Research Conclusion

Based on the perspective of innovation value chain, this study divides technological innovation into research and development and results transformation stages. Taking Shanghai and Shenzhen A-share new energy listed companies from 2016 to 2021 as research samples, it analyzes the impact of urban digital economy development on the two-stage innovation efficiency of new energy enterprises, and reveals the moderating role of organizational inertia and entrepreneurship between the two. The research conclusions are as follows:

First, the development of digital economy has significantly improved the efficiency of two-stage innovation of new energy enterprises. At the stage of research and development, digital economy can reduce the threshold for enterprises to obtain innovative resources, expand enterprise financing channels, and strengthen information sharing and technology linkage across disciplines and fields; In the results transformation stage, the digital economy helps new energy enterprises to identify energy consumer preferences, reduce consumer search and matching costs, and expand the new energy foreign trade market, so as to realize the two-stage innovation efficiency improvement.

Second, organizational inertia and entrepreneurship have a significant positive moderating effect on the relationship between the digital economy and the two-stage innovation efficiency of new energy enterprises. In the stage of research and development, organizational inertia can help enterprises identify scarce innovative resources and cooperation objects, ensure the reliability of R&D resources and the demand for resource integration. Entrepreneurship will urge enterprises to use the digital economy to imitate the R&D model of advanced enterprises, and reasonably allocate R&D resources among innovation entities; At the stage of results transformation, certain organizational inertia ensures the stable cooperation between upstream and downstream enterprises in the industrial chain, promotes the innovation of enterprise business models, and at the same time, certain entrepreneurial spirit can promote enterprises to use digital technology tools to identify the market value of research and development achievements, and be brave to use digital economy to pursue the renewal of business models.

Thirdly, the impact of the development of digital economy on the innovation efficiency of new energy enterprises at the stage of research and development and results transformation is different in regions, urban class and population size, and enterprise nature. In the stage of research and development, the development of urban digital economy can bring more technological innovation efficiency to the eastern and western regions, key cities and state-owned enterprises. At the stage of achievements transformation, the development of urban digital economy will play a greater role in promoting the technological innovation efficiency of state-owned enterprises in the central and eastern regions, key cities, with a population size of 5 million or more.

6.2. Main Enlightenment

This study has the following implications for the innovative practice of new energy enterprises: First, promote the digital economy to become the continuous driving force of technological innovation of new energy enterprises, and realize the simultaneous progress of research and development and achievements transformation. On the one hand, we will promote the construction of a new energy digital innovation system, establish a national laboratory for the research of the new generation of new energy systems and a micro-grid industrial park for cooperation between schools and enterprises, and realize cross-disciplinary and cross-domain information sharing and technology linkage. At the same time, we should guide traditional financial institutions to adapt to the development trend of the digital economy, improve the risk compensation and dispersion mechanism of new energy enterprise credit business through financial product innovation, and encourage the rapid development of Internet finance in the era of digital economy, such as angel investment and venture capital fund of "Green Energy Treasure", to help new energy enterprises break through the financing constraints. On the other hand, to guide new energy enterprises to use digital technology and digital information to improve the interaction between supply and demand, the government needs to accelerate the establishment of a series of achievements transformation and trading platforms such as the new energy technology trading center relying on digital technology, accelerate the launch of a market-oriented, shared and digital P2P new energy trading market, accelerate the installation of distributed solar and wind power generation equipment, and promote the transformation of industrial innovation achievements.

Secondly, in the era of digital economy, the government should actively create a good business environment to improve the ability of enterprises to take risks and operate and manage, encourage new energy enterprises to take the digital economy express, seek the allocation and reorganization of elements inside and outside the enterprise, upstream and downstream of the industry with the help of the Internet and big data, and carry out technical research. At the same time, new energy enterprises should maintain a stable and sustained attitude toward technological innovation decisions. New energy enterprises' machinery and equipment and other assets have strong specificity. A sustainable and stable digital economy innovation drive path can not only reduce opportunistic behavior in R&D cooperation, but also play the cumulative effect of existing technology tracks and innovation resources, effectively resist investment risks.

Finally, it is necessary to adjust measures to local conditions. The eastern region, key and large-scale cities should rely on the mature data element market and talents to optimize the innovation environment of the digital economy and achieve special breakthroughs in the field of new energy technology. For the central and western regions, general cities and small cities, we should not only make full use of our own advantages, but also combine the policies such as "Western Development in the New Era" and "Rise of Central China" with the new energy policies in the region, and give special preferential treatment to the development of new energy. In addition, we should narrow the digital gap with developed regions and cities by means of bridging the gap, guide high-end digital talents and social funds to flow to the digital economy industry in underdeveloped regions and cities, and build a user-centered digital service system. In terms of enterprises, policies should be implemented according to the classification of enterprise heterogeneity. The digital economy should continue to play its innovation dividend to state-owned new energy enterprises and lead the innovation development of the industry. The non-state-owned enterprises should further release their innovation vitality. The government should not only build a diversified lending market through the digital economy to benefit more vulnerable enterprises, but also share the conversion costs under the digital ecosystem with enterprises.

Disclosure Statement

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